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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)
MAR 78 M I VITENBERG

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# FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMATION AND COMMUNICATION

by

M. I. Vitenberg

FOREIGN TECHNOLOGY DIVISION





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By. M. I. Vitenberg

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## U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

| Block | Italic | Transliteration | Block | Italic | Transliteration |
|---|---|---|---|---|---|
| А а | *А а* | A, a | Р р | *Р р* | R, r |
| Б б | *Б б* | B, b | С с | *С с* | S, s |
| В в | *В в* | V, v | Т т | *Т т* | T, t |
| Г г | *Г г* | G, g | У у | *У у* | U, u |
| Д д | *Д д* | D, d | Ф ф | *Ф ф* | F, f |
| Е е | *Е е* | Ye, ye; E, e* | Х х | *Х х* | Kh, kh |
| Ж ж | *Ж ж* | Zh, zh | Ц ц | *Ц ц* | Ts, ts |
| З з | *З з* | Z, z | Ч ч | *Ч ч* | Ch, ch |
| И и | *И и* | I, i | Ш ш | *Ш ш* | Sh, sh |
| Й й | *Й й* | Y, y | Щ щ | *Щ щ* | Shch, shch |
| К к | *К к* | K, k | Ъ ъ | *Ъ ъ* | " |
| Л л | *Л л* | L, l | Ы ы | *Ы ы* | Y, y |
| М м | *М м* | M, m | Ь ь | *Ь ь* | ' |
| Н н | *Н н* | N, n | Э э | *Э э* | E, e |
| О о | *О о* | O, o | Ю ю | *Ю ю* | Yu, yu |
| П п | *П п* | P, p | Я я | *Я я* | Ya, ya |

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

## RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

| Russian | English | Russian | English | Russian | English |
|---|---|---|---|---|---|
| sin | sin | sh | sinh | arc sh | $\sinh^{-1}$ |
| cos | cos | ch | cosh | arc ch | $\cosh^{-1}$ |
| tg | tan | th | tanh | arc th | $\tanh^{-1}$ |
| ctg | cot | cth | coth | arc cth | $\coth^{-1}$ |
| sec | sec | sch | sech | arc sch | $\mathrm{sech}^{-1}$ |
| cosec | csc | csch | csch | arc csch | $\mathrm{csch}^{-1}$ |

| Russian | English |
|---|---|
| rot | curl |
| lg | log |

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# Chapter Five.

## CALCULATION OF THE AMPERE-TURNS OF STANDARD RELAYS.

### 5-1. Analytical method of the calculation of ampere-turns.

For determining the ampere-turns of the function of relay, loaded by any contact system, it is necessary to construct mechanical load line and to find force $F_1$ and clearance $\delta_1$, the corresponding to critical point electromechanical characteristics (Fig. 4-25). Critical points usually lie/rest on the flanges of mechanical characteristics; therefore critical point can be easily found that on having the electromechanical characteristics of relay. If mechanical characteristic has two flanges, then calculation is necessary to carry out for both points, since it is often difficult to predict, which of them is critical.

If are known values $F_1$ and $\delta_1$, then the reference values of the ampere-turns of the function of relay within the limits of the straight portions of full-load saturation curves can be determined with the aid of formulas (4-74), (4-75) or (4-77).

The more precise value of the ampere-turns of the function of relay can be obtained from formula (4-23), if is known the value of magnetic flux $\Phi_{l1}$ in clearance, necessary for the function of relay. Substituting value $\Phi_l$ in formulas (4-15), (4-15a) and (4-15b), we determine the value of magnetic flux at several points and we find the value of average resistor/resistance 1 m of the length of magnetic circuit and value of coefficient of q. [If average permeability is small, then more accurate results gives formula (4-31)].

For determining the ampere-turns of the function of relay from equation (4-23) we find the following expression:

$$AW = \frac{2\Phi_{l1}\left[l(R_m + R_0 R_{m1} g) + q(R_{m1} + R_0)\right]}{R_0 g l + 2}, \qquad (5\text{-}1)$$

where $R_{m1}$ - the reluctance, which corresponds to critical point $\delta_1$.

If the resistor/resistance of joints can be disregarded ($R_0$ = 0), then

$$AW = \Phi_{l1}(lR_m + gR_{m1}). \qquad (5\text{-}2)$$

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Ampere-turns necessary for conducting the magnetic flux through the clearance and the magnetic circuit

$$AW_{\delta} = \Phi_{l1} R_{\delta 1} \quad (5\text{-}3)$$

and

$$AW_{м} = AW - AW_{\delta}. \quad (5\text{-}4)$$

The analytical method of the calculation of the ampere-turns of function, presented above, it can be used for the calculation of relay of any type, but this method is sufficiently complex and requires too much time. During the development of equipment for automation, it is necessary to determine the ampere-turns of function for a large quantity of relays usually of one type, loaded by different contact groups. For the relay, operating in complex conditions/modes, furthermore, it is necessary to also determine the ampere-turns of failure, retention and release/tempering. A quantity of different contact groups (packets) of relay is sufficiently great. Of 15 fundamental contact groups of relay of the type BPN, can be assembled

more than 800 different contact packets. In present time for relay of the type RPN, it is released about 270 contact packets, for relay of the type RKN, - 200 and for relay of type 100 - it is more than 100 contact groups.

Therefore for mass calculations of the ampere-turns of standard relays, analytical method is completely unacceptable. In such cases usually are applied simpler - the tabular or graphic calculation methods, which make it possible rapidly and sufficient to accurately determine the ampere-turns of the function of the standard relays, loaded by any combination of contact groups.

Before passing to the examination of these calculation methods, let us pause preliminarily at the safety factors, which play large role during the determination of the certified/rating and working ampere turns of relay.

## 5-2. Safety factors.

Tables and calculated curves for determining the ampere-turns of function and release usually are composed

experimentally on the basis of the measurements of a large quantity of specimen/samples of relay.

, Electromagnetic relays are manufactured under conditions of large-scale production in essence fcr IV to the class of precision.

The value of the ampere-turns of function and release/tempering of relay depends on a large quantity of different factors (tolerances in size of parts, accuracy of assembly, fluctuations of the quality of materials and thickness of coatings, deviations of the regulating parameters and so forth). Therefore the distribution of the values of the current (ampere-turns) of function and release of relay obeys the law normal random number distribution.

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For parameter determination of the current distribution of function and current of the release/tempering of relay, it is necessary to measure not less than 30-50 specimen/samples of the relay of one and the same performance (certificate).

Figure 5-1a gives differential distribution curves according to spill current and the current of the release/tempering of relay of the type RES6 (winding impedance 2500 ohm ± 10o/o, turn number 12000), constructed by means of the grouping of the points of histograms on 6 intervals. Along the axis of ordinates, is deposit/postponed experimental probability density $m/M_0d$, where m is a quantity of specimen/samples in this interval of current, $M_0$ is the total quantity of measured specimen/samples ($M_0$ = 39) and d - a value of interval (d = 1).

From these curves it follows that the mathematical expectation (average weighted" on probabilities value) of the spill current of relay RES6 is equal to $\bar{I}_c = 13{,}3$ to mA, and the current of release/tempering $\bar{I}_0$ = 7.75 mA. The root-mean-square deviation of the spill current of this relay is equal to $\sigma_c = 1{,}14$ to mA (8.6o/o), and of the current of release/tempering $\sigma_{0}$ = 1.1 mA (14.2o/o).

The specimen/samples of the relays, which have spill current are more nominal (indicated in certificate) and the current of release/tempering the less than nominal, usually they are rejected during production. Therefore distribution curves frequently have the "truncated" character.

In such cases for parameter determination of distribution, it is more convenient to use the integral distribution curves, plotted on probabilistic grid, since the curve of normal random number distribution on probability grid is a straight line. The mathematical expectation of current is defined on straight line with $M/M_0$ = 50o/o., and root-mean-square deviation is located as reduction in current during a change in the quantile per unit: $M/M_0$ = 15.9o/o.

Figures 5-1b gives integral distribution curves according to the current of release/tempering and the spill current of relays of the type RES6 constructed according to nongrouped points.

Along the axis of abscissas, are deposit/postponed the quantiles of the normal distribution k and the probability of obtaining the specimen/samples of relay with the datum of the spill current or release/tempering $M/M_0$, where M is a total quantity of specimen/samples, having the spill current or release/tempering not of the more corresponding value on the axis of ordinates and $M_0$ is the total quantity of measured specimen/samples ($M_0$ = 39).

From the curves of Fig. 5-1b, it follows that the distribution of relay according to spill current and the current of release/tempering is virtually subordinated to normal law. With probability 0.995 ($\sigma$ = 2.6) the value of the spill current of relay is within the limits from 10.3 to 16.3 mA (according to certificate $I_0 \leq 20$ mA), and the value of the current of release/tempering is from 5.0 to 10.5 mA (on certificate $I_0 \geqslant 3$ mA). The great deviation of spill current from average value (with $2.6\sigma$) does not exceed ±22.6o/o, but of the current of release/tempering ±35.5o/o. smallest value of the spread of spill current have the relay of the type RES6 ±(6-11)o/o and of the relay of the type RES10 ±(13-15)o/o.

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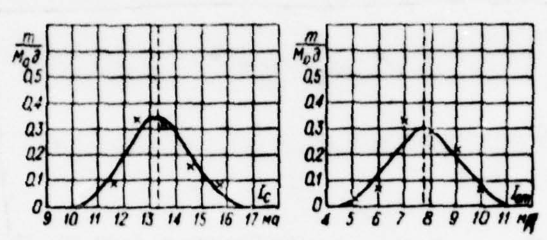

Fig. 5-1a. Differential distribution curves according to spill current and current of release/tempering of relay of type RES6.

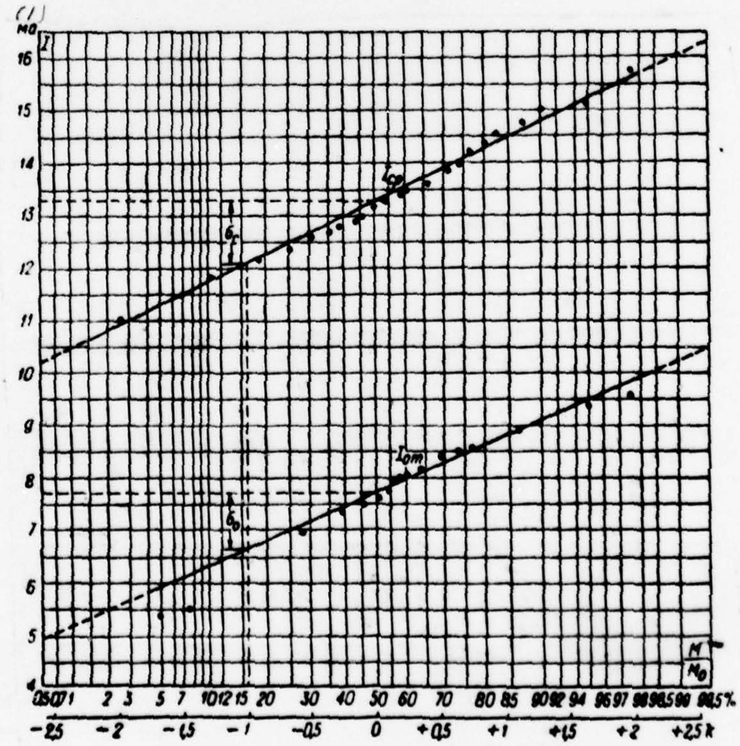

Fig. 5-1b.

Fig. 5-1b. Integral distribution curves according to spill current and current of release/tempering of relay of type RES6.

Key: (1) mA.

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The value of the spill current of the different types of relay under normal conditions can be deflected to ±(10-30) o/o from average value, while the value of the current of release/tempering - for ±(35-75) o/o. To the account for these fluctuations in the certificates of relay, usually are enter/written the spill currents and release, which differ from average values for the values, determined by the appropriate safety factors.

The safety factor on the ampere-turns of function is the ratio of working ampere-turns to the ampere-turns of the function of relay.

If magnetic relay circuit on is saturated, then attracting force can be considered the approximately proportional to the square of ampere-turns. In this case the relationship/ratio between the safety factors on attracting force $K_p$ and on ampere-turns $K_1$ will be

expressed by the following formula:

$$K_p = K_1^2. \quad (5\text{-}5)$$

In the case of the approach/approximation of steel to saturation, the exponent $K_1$ decreases.

The safety factors, caused by production tolerances, are called the production or certified/rating safety factors. Working ampere-turns, i.e., ampere-turns, obtained relays in the operating equipment, must differ from those who were indicated in certificate so in order to ensure necessary speed of response and the reliability of the operation of relay with fluctuations of the voltage of battery, changes in the load of armature and increases of the resistor/resistance of the circuit of winding, possible under operating conditions.

Thus, it is necessary to distinguish two safety factors: 1) certified/rating and 2) working.

a) Certified/rating safety factor.

The value of the certified/rating safety factor depends

on technology of the production of relay and is establish/installed experimentally.

Usually in the certificate of relay, the safety factor on the ampere-turns of function and failures is taken as equal to 1.15-1.3, but on the ampere-turns of release/tempering and retention 1.5-2.5.

For the different types of relay, the safety factors have different value.

In the certificates of relay of the type RKMP, are accepted the safety factors on the ampere-turns of function 1.2-1.3 and on ampere-turns from release 1.5-1.7. For the relay of types RS-52 and RMU, the safety factors in certificate on the ampere-turns of function are accepted equal to 1.15-1.3, also, on the ampere-turns of release/tempering 2.0-2.5. The first values of the safety factors are related to production (in-plant) certificate, the second - to operating.

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For relay of the type RS-13, rating safety factor on the

ampere-turns of function is taken as equal to 1.22, and on the ampere-turns of retention, release/tempering and failures equal to 1.6. Of the relay of types RPN and of RKM, the certified/rating safety factor is laid in design schedules and curves; therefore computed values of the ampere-turns of these types of relay are enter/written in certificates without supplementary reserves.

b) Working safety factor.

Depending on work conditions in the circuits of relay, they can be divided to two groups: voltage relays, connected directly (in parallel) to the common feed circuit, and current relays, connected in series with different instruments (for example the anode relays, linear so forth).

For voltage relay, the working safety factor on the actuation voltage depends on the fluctuations of supply voltage, tolerance level for winding impedance of relay, changes in winding impedance as a result of its heating and increases in the spill current of relay during changes in the load of armature.

The value of the working coefficient of the reserve of relay on stress it is possible to present in the form of the following formula:

$$K_u = \frac{k_y k_r k_\theta}{k_н}, \quad (5\text{-}6)$$

where $k_H$ is the coefficient, which considers possible decrease in supply voltage; $k_T$ is the coefficient, which considers an increase in the spill current of relay under the changes in the adjustment, the influence of uniform accelerations and impacts, and also with decrease in surrounding temperature and increase in the humidity; $k_r$ is the coefficient, which considers the probable deviation (increase) of winding impedance of relay at normal temperature from nominal value; $k_\theta$ is the coefficient, which considers an increase in winding impedance of relay as a result of a change in the temperature of surrounding air and overheating of winding under the action through it of the current taking place.

A change in supply voltage usually does not exceed ±10o/o, in certain cases the tolerance increases to 15-20o/o. With tolerance level ±10o/o coefficient $k_н \geqslant 0,9$. An

increase in the spill current of relay under the influence of uniform accelerations and impacts largely does not exceed 10-20o/o, but during changes in the ambient temperature and humidity 10o/o.

The value of coefficient $k_y$ strongly depends on the construction of relay, values of accelerations and fluctuations of temperature; therefore it can change within sufficiently wide limits. In the majority of cases, it is possible to accept $k_y \approx 1.2$.

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It is necessary to note that the virtually actual value of the safety factor on spill current, as is evident from Fig. 5-1a, approximately in 50o/o of relay of this party/batch, will be to 15-30o/o more, but in 90o/o of relay to 10-15o/o more value $k_y$.

Production tolerance for the value of winding impedance of relay under normal conditions (+20°C) usually does not exceed ±10o/o, tolerance for winding impedance from very fine/thin wires (0.03-0.09 mm) is frequently establish/installed equal to ±15o/o. With tolerance for

winding impedance $\pm$10o/o value $k_r \leqslant 1,1$.

The value of coefficient $k_\theta$ can be determined from formula (9-13), namely:

$$k_\theta = 1 + \alpha(\Theta - \Theta_0) = 1 + \frac{\vartheta}{234,5 + \Theta_0} = 1 + \frac{\vartheta}{254,5}, \quad (5\text{-}7)$$

where $\vartheta$ - average temperature excess of the winding of the relay above the normal temperature of surrounding air $\Theta_0$ = 20°C.

With ambient temperature of +85°C and the overheating of the winding of the relay above this temperature, equal to 35°C, value $\vartheta$ = 100°C and the value of coefficient $k_\theta = 1,394$. In this case the great value of the working coefficient of the reserve of relay on stress will be equal to:

$$K_u = \frac{1,2 \cdot 1,1 \cdot 1,394}{0,9} = 2,04.$$

If relay works under stationary conditions at temperature of +85°C, then, by set/assuming $k_\vartheta = 1$, we will obtain great value $K_u = 1,7$.

For current relay, the value of the working safety factor on the current (ampere-turns) of function $K_i$ depends on a possible increase in the spill current as a result

of changes in the adjustment, effect of uniform accelerations and impacts, and also a temperature decrease and increase in the humidity. Under the influence of vibration overloadings and the increase in the temperature, the spill current of relay decreases (§ 12-1 and 12-3).

With respect to the minimum possible value of circuital current of relay, value $K_1$ must be not less than 1.2-1.3. In many instances is sufficient to accept $K_1$ = 1.2, since the virtually actual value of the safety factor on current in 90o/o of relay will be to 10-15o/o more. If necessary of providing maximum possible speed of response of relay, the value of the actual safety factor on spill current must be within the limits approximately from 1.5 to 1.8.

The working safety factors with respect to the certified/rating values of ampere-turns for the relay, working in telephone circuits, must be not less: a) during function - 1.6; b) during retention - 1.3; h) with release/tempering - 1.4 and d) failure - 1.3.

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5-3. Tabular method of determining the ampere-turns.

The simplest method of determining the ampere-turns of the function of release/tempering, retention and failure of standard relays, loaded by different contact groups, is tabular method.

The tables of ampere-turns are composed experimentally on the basis of the measurements of a large quantity of specimen/samples of the relays, loaded by different contact groups.

Measurements are conducted by the different nominal values of the drift of armature and height/altitude of plugs.

The ampere-turns of the function of relay are determined at the moment of the complete attraction of armature.

Ampere-turns of the failure of fixing at the moment of the disappearance of the gap between armature and the driving plugs of contact groups.

The ampere-turns of retention are determined into that torque/moment, when armature begins to move. The obtained ampere-turns increase by 5o/o.

The ampere-turns of release/tempering are counted off at the onset of a gap between armature and the driving/moving plug of contact groups.

In tables usually they are brought mean values of ampere-turns taking into account production tolerances.

a) Principle of the construction of table for determination of the ampere-turns of relay of the type RPN.

Table for determining the ampere-turns of function, failure, retention and release/tempering of relay of the type RPN contains all the possible combinations for 15 fundamental contact groups; the number of combinations of these groups (packets) is equal to 813.

A relay of the type RPN can have three different courses of armature and four different nonmagnetic antistick strips; therefore table contains a total of 4732 different combinations of contact groups with different courses of armature and different nonmagnetic antistick strips.

The principle of the construction of table for determining the ampere-turns of relay of the type RPN is shown on table 5-1, where is given the small part of this table - only for relay with one, two and three groups for closing/shorting (group a).

Complete table for determining the ampere-turns of relay of the type RPN is not given, since it is very great (Table it contains 4732 rows). Furthermore, it for the ampere-turns of release/tempering and retention frequently gives insufficiently accurate results.

the presence in the table of the separate values of the ampere-turns of function for improved steel also cannot be justified, since the effect of the permeability of steel on the ampere-turns of function is considerably less than the effect of an inaccuracy in the production of parts, assembly and adjustment of relay.

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Table 5-1. Table for determination of the ampere-turns of relay of the type RPN.

| (1) Ход якоря, мм | (2) Пластина отлипания, мм | (3) Обозначение первой контактной группы а (01); (8) Обозначение контактных групп: (9) второй | (10) третьей | (4) Ампер-витки срабатывания: (11) Нормальное реле | (12) Реле повышенной точности | (5) Ампер-витки несрабатывания | (6) Ампер-витки удержания после предварительного подмагничивания ампер-витками, равными: 100 | 150 | 200 | 300 | 1000 | (7) Ампер-витки отпускания после предварительного подмагничивания ампер-витками, равными: 100 (+2) 150 (+1) 200 (+0) | 300 | 1000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,1 | 0,1 | 000 | 000 | 000 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| | 0,2 | 000 | 000 | 90 | 79 | 50 | 35 | 29 | 27 | 00 | 00 | 13 | 00 | 00 |
| | 0,3 | 000 | 000 | 94 | 83 | 53 | 48 | 40 | 38 | 00 | 00 | 19 | 00 | 00 |
| | 0,5 | 000 | 000 | 100 | 91 | 61 | 77 | 60 | 57 | 55 | 54 | 32 | 31 | 30 |
| 1,3 | 0,1 | 000 | 000 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| | 0,2 | 000 | 000 | 97 | 86 | 54 | 38 | 31 | 29 | 00 | 00 | 13 | 00 | 00 |
| | 0,3 | 000 | 000 | 103 | 92 | 58 | — | 42 | 40 | 38 | 00 | 20 | 20 | 00 |
| | 0,5 | 000 | 000 | 116 | 105 | 64 | — | 64 | 61 | 59 | 58 | 34 | 33 | 32 |
| 1,5 | 0,1 | 000 | 000 | 00 | 90 | 00 | — | 00 | 00 | 00 | 00 | 000 | 00 | 00 |
| | 0,2 | 000 | 000 | 106 | 95 | 65 | — | 30 | 28 | 00 | 00 | 15 | 00 | 00 |
| | 0,3 | 000 | 000 | 112 | 101 | 68 | — | 41 | 39 | 37 | 36 | 21 | 20 | 20 |
| | 0,5 | 000 | 000 | 125 | 113 | 75 | — | 62 | 59 | 57 | 56 | 35 | 34 | 34 |
| 1,1 | 0,1 | a | 000 | 114 | 103 | 66 | — | 28 | 26 | 00 | 00 | 17 | 00 | 00 |
| | 0,2 | a | 000 | 120 | 108 | 71 | — | 55 | 51 | 49 | 48 | 26 | 25 | 25 |
| | 0,3 | a | 000 | 126 | 114 | 77 | — | 70 | 65 | 53 | 62 | 36 | 34 | 34 |
| | 0,5 | a | 000 | 143 | 129 | 87 | — | 113 | 95 | 90 | 88 | 57 | 55 | 53 |
| 1,3 | 0,1 | a | 000 | 126 | 114 | 73 | — | 32 | 30 | 00 | 00 | 17 | — | — |
| | 0,2 | a | 000 | 136 | 124 | 77 | — | 61 | 56 | 54 | 53 | 26 | 25 | 25 |
| | 0,3 | a | 000 | 147 | 133 | 82 | — | 77 | 71 | 68 | 66 | 36 | 34 | 34 |
| | 0,5 | a | 000 | 168 | 153 | 90 | — | — | 103 | 97 | 94 | 57 | 55 | 54 |
| 1,5 | 0,1 | a | 000 | 142 | 129 | 87 | — | 31 | 29 | — | — | 17 | — | — |
| | 0,2 | a | 000 | 152 | 138 | 92 | — | — | 54 | 52 | 51 | 26 | 25 | 25 |
| | 0,3 | a | 000 | 162 | 147 | 97 | — | — | 68 | 65 | 64 | 36 | 35 | 36 |
| | 0,5 | a | 000 | 186 | 171 | 106 | — | — | 100 | 94 | 91 | 58 | 56 | 55 |
| 1,1 | 0,1 | a | a | 139 | 126 | 82 | — | 46 | 42 | 41 | 40 | 24 | 23 | 23 |
| | 0,2 | a | a | 147 | 133 | 88 | — | 85 | 75 | 73 | 71 | 33 | 32 | 31 |
| | 0,3 | a | a | 156 | 140 | 95 | — | — | 97 | 90 | 88 | 47 | 46 | 45 |
| | 0,5 | a | a | 188 | 172 | 108 | — | — | 155 | 132 | 124 | 72 | 71 | 70 |
| 1,3 | 0,1 | a | a | 163 | 146 | 89 | — | — | 45 | 44 | 43 | 25 | 24 | 24 |
| | 0,2 | a | a | 179 | 162 | 95 | — | — | 81 | 79 | 77 | 34 | 33 | 32 |
| | 0,3 | a | a | 195 | 179 | 101 | — | — | 106 | 97 | 95 | 48 | 47 | 46 |
| | 0,5 | a | a | 231 | 213 | 112 | — | — | — | 145 | 135 | — | 76 | 71 |
| 1,5 | 0,1 | a | a | 185 | 171 | 109 | — | — | 44 | 43 | 42 | 26 | 25 | 25 |
| | 0,2 | a | a | 202 | 186 | 114 | — | — | 79 | 77 | 75 | — | 35 | 34 |
| | 0,3 | a | a | 220 | 204 | 120 | — | — | 102 | 94 | 92 | — | 49 | 48 |
| | 0,5 | a | a | 266 | 250 | 132 | — | — | 171 | 140 | 130 | — | 77 | 75 |

Key: (1). Course of armature, mm. (2). Nonmagnetic antistick strip, mm. (3). Designation of the first contract group. (4). Ampere-turns of function. (5). ampere-turns of failure. (6). Ampere-turns of retention after preliminary magnetic biasing by the ampere-turns, equal. (7). Ampere-turns of release/tempering after preliminary magnetic biasing by the ampere turns, equal. (8). Designation of contact groups. (9). the second. (10). by the third. (11). Normal relay. (12). Relays of the increased accuracy.

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The ampere-turns of new contact groups (No 95, 103, 105, 106 and 107) cannot be determined with the aid of this table.

Therefore for determining the ampere-turns of relay of the type RPN, it is better to use the method of equivalent loads which will be examined below.

b) Table for determining the ampere-turns of relay of type RKM-1.

For determining the ampere-turns of function, release/tempering, retention and failure of relay of type rkm-1 table 5-2 and 5-3 gives the appropriate values of ampere-turns at the load of relay by different contact groups, the course of armature 1.1 mm and the height/altitude of plugs 0.1 and 0.2 mm.

These tables contain ampere-turns for 37 contact packets which are manufactured at present.

c) Table for determining the ampere-turns of relay of the type RES14.

Table 5-4 gives the tentative values of the ampere-turns of function, failure, retention and release/tempering with some loads for a new relay of the type RES14.

From foregoing it follows that the tabular calculation method, being simplest with a small quantity of contact packets, it becomes very bulky with a large quantity of fundamental contact groups. Therefore recently for the calculation of the ampere-turns of standard relays widest use received the graphic calculation methods.

Table 5-2. Table for determining the ampere-turns of relay of type RKN-1 with the return spring of armature).

| (1) Обозначение контактных групп | | | (2) Штифт 0,1 мм | | | | (3) Штифт 0,2 мм | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| III | II | I | (4) Срабатывание | (5) Отпускание | (6) Удержание | (7) Несрабатывание | (4) Срабатывание | (5) Отпускание | (6) Удержание | (7) Несрабатывание |
| — | а | — | 110 | 30 | 60 | 35 | 120 | 40 | 80 | 45 |
| — | г | — | 110 | 25 | 55 | 40 | 120 | 30 | 75 | 50 |
| — | и | — | 110 | 30 | 60 | 50 | 120 | 40 | 80 | 45 |
| а | — | а | 120 | 40 | 80 | 50 | 135 | 50 | 110 | 50 |
| а | — | г | 130 | 35 | 80 | 55 | 150 | 55 | 90 | 60 |
| г | — | г | 130 | 30 | 90 | 50 | 180 | 35 | 100 | 55 |
| г | — | и | 135 | 40 | 80 | 45 | 160 | 40 | 110 | 50 |
| и | — | и | 130 | 35 | 90 | 40 | 140 | 55 | 110 | 55 |
| а | а | а | 150 | 50 | 100 | 55 | 170 | 65 | 130 | 60 |
| а | г | а | 150 | 45 | 110 | 55 | 170 | 60 | 120 | 60 |
| г | и | а | 170 | 45 | 100 | 55 | 190 | 60 | 120 | 65 |
| г | а | г | 170 | 45 | 120 | 55 | 190 | 60 | 150 | 70 |
| г | и | г | 180 | 40 | 90 | 55 | 200 | 55 | 120 | 65 |
| и | и | и | 160 | 40 | 100 | 40 | 175 | 55 | 135 | 55 |
| и | а | и | 150 | 50 | 100 | 55 | 170 | 60 | 135 | 60 |
| и | г | и | 160 | 40 | 110 | 60 | 170 | 55 | 120 | 65 |
| а | а<br>г | а | 175 | 50 | 120 | 60 | 190 | 65 | 140 | 65 |
| и<br>а | — | и<br>а | 175 | 55 | 110 | 60 | 210 | 65 | 140 | 70 |
| г | а<br>а | и | 190 | 50 | 110 | 65 | 200 | 65 | 135 | 70 |
| и | и<br>а | и | 180 | 55 | 150 | 55 | 195 | 65 | 160 | 65 |
| и | г<br>а | и | 175 | 50 | 120 | 65 | 200 | 60 | 150 | 70 |
| а<br>г | — | а<br>г | 195 | 50 | 110 | 65 | 200 | 65 | 140 | 70 |
| г | и<br>а | г | 190 | 50 | 150 | 60 | 210 | 65 | 160 | 70 |
| г | г<br>г | г | 220 | 45 | 150 | 65 | 240 | 50 | 150 | 70 |
| и | г<br>г | и | 200 | 45 | 150 | 60 | 220 | 65 | 160 | 70 |
| и | г<br>и | и | 180 | 50 | 150 | 65 | 220 | 60 | 160 | 70 |
| а<br>а | а | а<br>а | 190 | 60 | 130 | 80 | 210 | 75 | 150 | 70 |
| а<br>а | г | а<br>а | 190 | 70 | 135 | 70 | 210 | 70 | 160 | 75 |
| г<br>а | а | г<br>а | 200 | 55 | 115 | 60 | 220 | 70 | 165 | 70 |
| и | а<br>и | г<br>г | 220 | 55 | 150 | 95 | 245 | 65 | 190 | 65 |
| а<br>и | и | г<br>и | 210 | 55 | 130 | 70 | 220 | 70 | 170 | 75 |
| а<br>а | а<br>а | а<br>а | 220 | 75 | 130 | 75 | 240 | 80 | 170 | 75 |
| а<br>а | а<br>и | а<br>а | 220 | 65 | 150 | 65 | 245 | 70 | 200 | 75 |
| а<br>и | а<br>и | а<br>и | 240 | 65 | 170 | 70 | 250 | 80 | 190 | 80 |
| г<br>и | г<br>и | г<br>и | 270 | 60 | 170 | 75 | 290 | 70 | 220 | 80 |
| а<br>г | а<br>г | а<br>г | 240 | 60 | 150 | 70 | 260 | 75 | 170 | 80 |
| а<br>и | а<br>г | а<br>и | 230 | 60 | 180 | 70 | 250 | 75 | 200 | 80 |

Key: (1). Designation of contact groups. (2). Plug 0.1 mm. (3). Plug 0.2 mm. (4). Function. (5). Release/tempering. (6). Retention. (7). Failure.

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Table 5-3. Table for determining the ampere-turns of relay of type RMK-1 (without the return spring of armature).

| (1) Обозначение контактных групп | | | (2) Штифт 0,1 мм | | | | (3) Штифт 0,2 мм | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| III | II | I | (4) Срабатывание | (5) Отпускание | (6) Удержание | (7) Несрабатывание | (4) Срабатывание | (5) Отпускание | (6) Удержание | (7) Несрабатывание |
| — | а | — | 80 | 15 | 60 | 15 | 90 | 20 | 70 | 15 |
| — | г | — | 80 | 5 | 45 | 20 | 90 | 10 | 55 | 20 |
| — | и | — | 90 | 10 | 50 | 15 | 95 | 15 | 55 | 25 |
| а | — | а | 110 | 20 | 70 | 30 | 120 | 30 | 85 | 30 |
| а | — | г | 100 | 20 | 55 | 30 | 115 | 35 | 75 | 35 |
| г | — | г | 115 | 15 | 60 | 35 | 125 | 25 | 65 | 40 |
| г | — | и | 105 | 20 | 55 | 30 | 115 | 30 | 70 | 35 |
| и | — | и | 125 | 20 | 65 | 25 | 125 | 35 | 80 | 30 |
| а | а | а | 130 | 40 | 85 | 35 | 140 | 55 | 100 | 45 |
| а | г | а | 125 | 30 | 75 | 45 | 130 | 50 | 95 | 40 |
| г | и | а | 130 | 30 | 80 | 45 | 140 | 45 | 95 | 50 |
| г | а | г | 140 | 30 | 70 | 45 | 150 | 45 | 90 | 50 |
| г | и | г | 145 | 25 | 75 | 50 | 155 | 35 | 95 | 50 |
| и | и | и | 145 | 30 | 85 | 35 | 150 | 45 | 105 | 45 |
| и | а | и | 125 | 35 | 80 | 40 | 135 | 50 | 100 | 45 |
| и | г | и | 135 | 30 | 80 | 35 | 145 | 40 | 100 | 50 |
| а | а<br>г | а | 155 | 45 | 100 | 55 | 170 | 60 | 120 | 55 |
| и<br>а | — | и<br>а | 155 | 45 | 95 | 50 | 165 | 60 | 120 | 55 |
| г | а<br>а | г | 155 | 40 | 90 | 45 | 165 | 60 | 105 | 55 |
| и | и<br>а | и | 160 | 40 | 100 | 50 | 170 | 60 | 125 | 55 |
| а<br>г | — | а<br>г | 165 | 40 | 95 | 55 | 175 | 60 | 105 | 60 |
| и | г<br>а | и | 165 | 40 | 95 | 50 | 175 | 55 | 120 | 60 |
| г | и<br>а | г | 165 | 35 | 90 | 50 | 180 | 55 | 110 | 60 |
| г | г<br>г | г | 190 | 30 | 80 | 60 | 200 | 35 | 105 | 60 |
| и | г<br>г | и | 180 | 35 | 90 | 55 | 190 | 50 | 120 | 60 |
| и | г<br>и | и | 165 | 45 | 100 | 55 | 185 | 60 | 125 | 70 |
| а<br>а | а | а<br>а | 175 | 55 | 105 | 55 | 185 | 70 | 130 | 60 |
| а<br>а | г | а<br>а | 175 | 50 | 105 | 60 | 185 | 65 | 130 | 65 |
| г<br>а | а | г<br>а | 185 | 50 | 105 | 50 | 200 | 65 | 125 | 65 |
| и | а<br>и | г<br>г | 200 | 45 | 110 | 60 | 210 | 60 | 140 | 70 |
| а<br>и | и | г<br>и | 190 | 50 | 115 | 60 | 200 | 60 | 135 | 65 |
| а<br>а | а<br>а | а<br>а | 200 | 60 | 160 | 65 | 215 | 65 | 150 | 70 |
| а<br>а | а<br>и | а<br>а | 200 | 60 | 125 | 65 | 220 | 60 | 155 | 70 |
| а<br>и | а<br>и | а<br>и | 220 | 60 | 130 | 65 | 230 | 75 | 165 | 70 |
| г<br>и | г<br>и | г<br>и | 250 | 45 | 125 | 65 | 275 | 60 | 155 | 75 |
| а<br>г | а<br>г | а<br>г | 225 | 50 | 125 | 60 | 240 | 65 | 150 | 70 |
| а<br>и | а<br>г | а<br>и | 210 | 50 | 130 | 65 | 230 | 70 | 165 | 75 |

Key: (1). Designation of contact groups. (2). Plug 0.1 mm. (3). Plug 0.2 mm. (4). Function. (5). Release/tempering. (6). Retention. (7). Failure.

Table 5-4. Table for determining the ampere-turns of relay of type RES [reticuloendothelial system ]-14.

| (1) Номер пакета | (2) Обозначение контактных групп | | | | | | (3) Пластина отлипания 0,1 мм | | | | (3) Пластина отлипания 0,2 мм | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | уз | ор | бп | з | р | п | (4) Срабатывание | (5) Отпускание | (6) Удержание | (7) Несрабатывание | (4) Срабатывание | (5) Отпускание | (6) Удержание | (7) Несрабатывание |
| 106 | — | — | — | 2 | — | — | 122 | 10 | 23,5 | 94 | 132 | 16 | 37,5 | 101 |
| 109 | — | — | — | — | 2 | — | 146 | 8,5 | 18,5 | 110 | 157 | 13,5 | 32,5 | 117 |
| 111 | — | — | — | — | — | 2 | 155 | 15,5 | 36,5 | 116 | 165 | 23,0 | 52 | 123 |
| 103 | — | — | — | 4 | — | — | 138 | 17,5 | 41 | 105 | 148 | 26,0 | 56,5 | 111 |
| 107 | — | — | — | — | 4 | — | 177 | 13,5 | 32,5 | 132 | 188 | 20,5 | 47 | 140 |
| 110 | — | — | — | — | — | 4 | 199 | 30 | 63,5 | 147 | 212 | 42,5 | 82,5 | 157 |
| 024 | — | — | — | — | — | 6 | 241 | 47 | 88,5 | 177 | 257 | 66,5 | 111,5 | 188 |
| 000 | — | — | — | 8 | — | — | 164 | 35 | 71 | 122 | 176 | 49 | 91 | 131 |
| 016 | — | — | — | — | 8 | — | 236 | 25,5 | 56 | 174 | 251 | 36,5 | 73,5 | 185 |
| 023 | — | — | — | — | — | 8 | 281 | 67 | 114 | 205 | 302 | 97,5 | 149 | 218 |
| 113 | — | — | — | 12 | — | — | 207 | 55,5 | 99,5 | 153 | 222 | 78,5 | 127 | 163 |
| 004 | — | — | — | 4 | 4 | — | 199 | 30 | 63,5 | 147 | 212 | 42,5 | 82,5 | 157 |
| 092 | 2 | — | — | — | — | 2 | 209 | 24,5 | 54,5 | 154 | 215 | 36,5 | 73,5 | 159 |
| 095 | — | 2 | — | — | — | 2 | 163 | 25,5 | 56 | 121 | 191 | 32,5 | 67 | 142 |
| 100 | — | 2 | 2 | — | — | — | 174 | 24 | 53,5 | 129 | 198 | 33 | 68 | 147 |
| 050 | 4 | — | — | 2 | — | — | 230 | 24,5 | 54 | 170 | 233 | 41 | 80 | 172 |
| 093 | — | 4 | — | — | — | 2 | 179 | 34 | 69,5 | 133 | 204 | 41 | 80 | 151 |
| 101 | — | — | 4 | — | — | — | 228 | 31 | 65,5 | 168 | 244 | 46 | 87 | 179 |
| 039 | — | — | 4 | 2 | 2 | — | 276 | 49,5 | 92 | 202 | 300 | 71 | 119 | 217 |
| 087 | — | — | 4 | — | — | 4 | 325 | 72,5 | 120 | 232 | 360 | 105 | 158 | 251 |

Key: (1). Number of packet. (2). Designation of contact groups. (3). Nonmagnetic antistick strip. (4). Function. (5). Release/tempering. (6). Retention. (7). Failure.

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5-4. Calculation of the ampere-turns of function and failure by the method of equivalent loads.

The dependence between the attracting force of the armature of relay and ampere turns with nominal clearance is expressed, as is known, by full-load saturation curve. However, the load, created by contact groups, is variable, it changes with a decrease in the clearance in the process of the armature travel of relay. Therefore for determining the ampere turns of the function of relay with the aid of full-load saturation curve, it is necessary the real varying load of the armature of relay to replace with the equivalent constant load for overcoming of which are required the ampere-turns, equal to the ampere-turns of the function of relay.

For determining the equivalent loads of any contact group, it is necessary to measure the average ampere-turns of function and failure of a large quantity of faultless thoroughly controlled relays. Measurements must be conducted by the different nominal values of the course of armature and height/altitude of plugs. Then from full-load saturation curves for different clearances are determined the loads in grams, which correspond to these average ampere-turns. The

average values of the obtained loads are accepted respectively as the equivalent loads of function and failure for this contact group.

a) Calculation of the ampere-turns of relay of the type RPN.

The contact packets of relay of the type RPN are collect/built of one, two or three fundamental contact groups whose quantity achieved at present 22 (contact groups No 95, 103, 105, 106 and 107 were developed recently and narrower were familiar in production).

For each fundamental contact group experimentally determined the equivalent loads of function and failure. The equivalent loads of function depend on clearance (course of armature and thickness of nonmagnetic antistick strip). The equivalent loads of failure can be considered not depending on the value of clearance.

Table 5-5 gives the equivalent loads of function and failure for 22 basic groups of relay of the type RPN.

The curves of the dependences of attracting force on ampere-turns for relay of the type RPN with different clearances are given in Fig. 5-2.

For determining the ampere-turns of function or failure of relay, it is necessary from table 5-5 to find the equivalent loads, which correspond to the basic groups of the contact packet of relay.

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Table 5-5. Equivalent loads of function and failure for relay of the type RPN (in grams).

| (3) Номер чертежа | (1) Контактные группы | | | (2) Эквивалентные нагрузки | |
|---|---|---|---|---|---|
| | (4) Обозначение группы | | (7) Схема | (8) Срабатывания | (9) Несрабатывания |
| | (5) старое | (6) новое | | $F_c$ | $F_н$ |
| 01 | *a* | *з* | | 39 | 10 |
| 02 | *r* | *p* | | 31 | 9,5 |
| 03 | *u* | *п* | | 32 | 9,5 |
| 04 | *za* | *cз* | | 39 | 10 |
| 05 | *zr* | *cp* | | 35 | 11,7 |
| 07 | *ar* | *зp* | | 49 | 9 |
| 10 | *rr* | *pp* | | 58 | 21 |
| 11 | *zra* | *cpз* | | 36 | 10 |
| 12 | *ur* | *cпp* | | 62 | 22 |
| 13 | *au* | *озп* | | 41 | 14 |
| 26 | *faa* | *озз* | | 33 | 3 |
| 27 | *far* | *озp* | | 34 | 3 |
| 28 | *fra* | *opз* | | 39 | 11 |
| 29 | *rza* | *pcз* | | 37 | 10,3 |
| 46 | *aa* | *зз* | | 52 | 7,5 |
| 95 | *afr* | *бп* | | 35 | 10 |
| 100 | *gru* | *pп* | | 57 | 21 |
| 102 | *gau* | *зп* | | 48 | 15 |
| 103 | *gzaa* | *cзз* | | 60 | 22 |
| 105 | *gua* | *бпз* | | 50 | 15 |
| 106 | *gur* | *бпp* | | 50 | 15 |
| 107 | *aaa* | *ззз* | | 72 | 26 |

Key: (1). Contact groups. (2). Equivalent loads. (3). Number of drawing. (4). Designation of group. (5). old. (6). new. (7). Circuit. (8). Functions. (9). Failures.

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Store/adding up the equivalent loads of all basic groups, we find the common/general/total equivalent load of relay. From full-load saturation curve for this clearance through the value of common/general/total equivalent load, we find the ampere-turns of the function of this relay. These ampere-turns of function can be written in the certificate of relay (without reserve), since equivalent loads table 5-5 gives taking into account production tolerances.

b) Calculation of the ampere-turns of relay type KN.

All the contact groups of relay of the type RKN are comprised of four simplest fundamental contact cell/elements: a) closing/shorting, b) interrupting, c) switching with interrupting before closing/shorting and d) switching with

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,5 | 0,1 | a | a | 185 | 171 | 109 | — | — | 44 | 43 | 42 | 26 | 25 | 25 |
| | 0,2 | a | a | 202 | 186 | 114 | — | — | 79 | 77 | 75 | — | 35 | 34 |
| | 0,3 | a | a | 220 | 204 | 120 | — | — | 102 | 94 | 92 | — | 49 | 48 |
| | 0,5 | a | a | 266 | 250 | 132 | — | — | 171 | 140 | 130 | — | 77 | 75 |



closing/shorting before interrupting. To each fundamental contact cell/element of group corresponds the equivalent load in grams whose value depends on the height/altitude of the plug of armature and total quantity of contact cell/elements nct of relay.

The equivalent loads of function and failure for the fundamental contact cell/elements of relay of the type RKN at the different height/altitude of plugs are given in table 5-6.

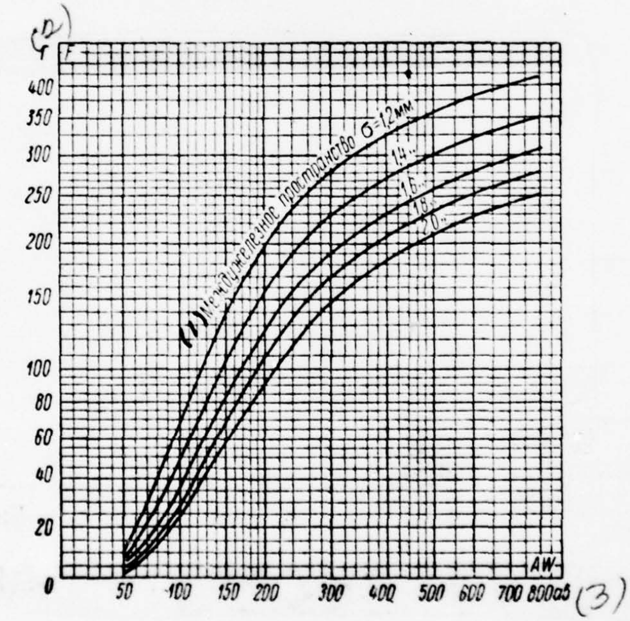


Fig. 5-2. Curved for determining ampere-turns of function and failure of relay of type RPN.

Key: (1). Clearance. (2). g. (3). AV.

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Table 5-6. Equivalent loads for relay of the type RKN (in grams).

| (3) Функции | (4) Число контактных элементов на реле | (5) Размыкание | | | | (6) Замыкание | | | | (7) Переключение | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (8) Высота штифта | | | | | | | | (9) Простое | | | | (10) Переходное | | | |
| | | | | | | | | | | (8) Высота штифта | | | | | | | |
| | | 0,1 мм | 0,2 мм | 0,3 мм | 0,5 мм | 0,1 мм | 0,2 мм | 0,3 мм | 0,5 мм | 0,1 мм | 0,2 мм | 0,3 мм | 0,5 мм | 0,1 мм | 0,2 мм | 0,3 мм | 0,5 мм |
| (2) Срабатывание | 1 | 46 | 46 | 53 | 54 | 26 | 27 | 36 | 41 | 46 | 46 | 53 | 54 | 39 | 41 | 45 | 46 |
| | 2 | 48 | 48 | 54 | 56 | 29 | 29 | 36 | 41 | 48 | 48 | 54 | 56 | 41 | 41 | 50 | 50 |
| | 3 | 50 | 51 | 54 | 59 | 30 | 30 | 38 | 42 | 50 | 51 | 54 | 59 | 44 | 44 | 50 | 53 |
| | 4 | 50 | 51 | 54 | 60 | 30 | 31 | 38 | 44 | 50 | 51 | 54 | 60 | 44 | 44 | 50 | 54 |
| | 5 | 50 | 51 | 54 | 60 | 30 | 31 | 38 | 44 | 50 | 51 | 54 | 60 | 44 | 44 | 50 | 54 |
| | 6 | 51 | 51 | 54 | 61 | 30 | 33 | 39 | 45 | 50 | 51 | 54 | 61 | 44 | 45 | 50 | 56 |
| | 7 | 51 | 53 | 54 | 63 | 30 | 33 | 39 | 45 | 51 | 53 | 54 | 63 | 44 | 45 | 50 | 57 |
| | 8 | 51 | 53 | 56 | 63 | 30 | 35 | 39 | 47 | 51 | 53 | 56 | 63 | 45 | 46 | 50 | 57 |
| (1) Несрабатывание | 1 | 18 | 18 | 19 | 20 | 8 | 8 | 8 | 8 | 18 | 18 | 19 | 20 | 8 | 8 | 8 | 8 |
| | 2 | 18 | 19 | 21 | 21 | 8 | 8 | 8 | 8 | 18 | 19 | 21 | 21 | 8 | 8 | 8 | 8 |
| | 3 | 19 | 20 | 21 | 22 | 8 | 8 | 8 | 8 | 19 | 20 | 21 | 22 | 8 | 8 | 8 | 8 |
| | 4 | 20 | 20 | 21 | 23 | 8 | 8 | 8 | 8 | 20 | 20 | 21 | 23 | 8 | 8 | 8 | 8 |
| | 5 | 20 | 20 | 21 | 23 | 8 | 8 | 9 | 9 | 20 | 20 | 21 | 23 | 8 | 8 | 9 | 9 |
| | 6 | 20 | 20 | 21 | 23 | 8 | 8 | 9 | 9 | 20 | 20 | 21 | 23 | 8 | 8 | 9 | 9 |
| | 7 | 20 | 20 | 21 | 24 | 8 | 8 | 9 | 9 | 20 | 20 | 21 | 24 | 8 | 8 | 9 | 9 |
| | 8 | 20 | 20 | 21 | 24 | 8 | 8 | 9 | 9 | 20 | 20 | 21 | 24 | 8 | 8 | 9 | 9 |

Key: (1). Failure. (2). Function. (3). ~~Day lily~~ Function. (4). Number of contact cell/elements on relay. (5). Interrupting. (6). Closing/shorting. (7). Switching. (8). Height/altitude of plug. (9). Simple. (10). Transient.

Table 5-7. Contact groups of the relay of the type RKN.

| (1) Номера контактных групп | (2) Количество основных контактных элементов | | | | (1) Номера контактных групп | (2) Количество основных контактных элементов | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (3) Замыкание | (4) Размыкание | (5) Переключение | | | (3) Замыкание | (4) Размыкание | (5) Переключение | |
| | | | (6) простое | (7) переходное | | | | (6) простое | (7) переходное |
| 1 | 1 | — | — | — | 11 | — | 1 | — | 1 |
| 2 | — | 1 | — | — | 12 | — | — | 2 | — |
| 3 | — | — | 1 | — | 13 | — | — | 1 | 1 |
| 4 | — | — | — | 1 | 14 | — | — | — | 2 |
| 5 | 2 | — | — | — | 15 | 3 | — | — | — |
| 6 | 1 | 1 | — | — | 16 | 2 | 1 | — | — |
| 7 | 1 | — | 1 | — | 17 | 2 | — | 1 | — |
| 8 | 1 | — | — | 1 | 18 | 2 | — | — | — |
| 9 | — | 1 | 1 | — | 19 | 1 | 2 | — | — |
| 10 | — | 1 | 1 | — | 20 | 1 | 1 | 1 | — |
| 28 | — | 1 | 2 | — | 38 | 3 | — | — | 1 |
| 29 | — | 1 | 1 | 1 | 39 | 2 | 2 | — | — |
| 30 | — | 1 | — | 2 | 40 | 2 | 1 | 1 | — |
| 31 | — | — | 3 | — | 41 | 2 | 1 | — | 1 |
| 32 | — | — | 2 | 1 | 42 | 1 | 3 | — | — |
| 33 | — | — | 1 | 2 | 43 | 1 | 2 | 1 | — |
| 34 | — | — | — | 3 | 44 | 1 | 2 | — | 1 |
| 35 | 4 | — | — | — | 45 | — | 4 | — | — |
| 36 | 3 | 1 | — | — | 46 | — | 3 | 1 | — |
| 37 | 3 | — | 1 | — | 47 | — | 3 | — | 1 |

**Key:** (1). Numbers of contact groups. (2). Quantity of fundamental contact cell/elements. (3). Closing/shorting. (4). Interrupting. (5). Switching. (6). simple. (7). transient.

Table 5-8. Equivalent loads of function for relay of the type RKMP (in grams).

| (1) Число контактных элементов на реле | (2) Размыкание | | | | (3) Замыкание | | | | (4) Переключение | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (5) Высота штифта | | | | | | | | | | | |
| | 0,05 мм | 0,1 мм | 0,2 мм | 0,3 мм | 0,05 мм | 0,1 мм | 0,2 мм | 0,3 мм | 0,05 мм | 0,1 мм | 0,2 мм | 0,3 мм |
| | (6) Сердечник с полюсным наконечником | | | | | | | | | | | |
| 1 | 49 | 49 | 51 | 52 | 30 | 32 | 35 | 36 | 49 | 49 | 51 | 52 |
| 2 | 52 | 52 | 54 | 55 | 30 | 32 | 36 | 37 | 52 | 52 | 54 | 55 |
| 3 | 52 | 53 | 54 | 55 | 31 | 33 | 36 | 37 | 52 | 53 | 54 | 55 |
| 4 | 53 | 54 | 54 | 55 | 31 | 35 | 36 | 40 | 53 | 54 | 54 | 55 |
| 5 | 53 | 54 | 56 | 57 | 32 | 35 | 37 | 42 | 53 | 54 | 56 | 57 |
| 6 | 53 | 54 | 56 | 57 | 33 | 36 | 40 | 42 | 53 | 54 | 56 | 57 |
| | (7) Сердечник без полюсного наконечника | | | | | | | | | | | |
| 1 | 43 | 45 | 48 | 51 | 20 | 22 | 22 | 25 | 43 | 45 | 48 | 51 |
| 2 | 43 | 48 | 51 | 52 | 20 | 23 | 24 | 25 | 43 | 48 | 51 | 52 |
| 3 | 46 | 48 | 51 | 52 | 20 | 23 | 25 | 28 | 46 | 48 | 51 | 52 |
| 4 | 49 | 50 | 52 | 53 | 21 | 23 | 26 | 30 | 49 | 50 | 52 | 53 |
| 5 | 50 | 51 | 52 | 53 | 21 | 24 | 26 | 30 | 50 | 51 | 52 | 53 |
| 6 | 50 | 51 | 52 | 53 | 21 | 24 | 26 | 30 | 50 | 51 | 52 | 53 |

Key: (1). Number of contact cell/elements not of relay. (2). Interrupting. (3). Closing/shorting. (4). Switching. (5). Height/altitude of plug. (6). Core with the pole piece. (7). Core without the pole piece.

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The curves of the dependences of attracting force on ampere-turns for a normal relay of the type RKN with clearances 0.7; 0.9; 1.0; 1.1; 1.2 and 1.3 mm are given in Fig. 5.3.

For the calculation of the ampere-turns of function or failure, it is necessary to determine first from table 5-7 types and the total number of fundamental contact cell/elements of relay, then from table 5-6 to find the appropriate values of equivalent loads at this height/altitude of plug for each cell/element individually. Store/adding up the equivalent loads of all cell/elements of relay and multiplying result for the safety factor on attracting force (or Dale him to the safety factor to failure), we obtain the common/general/total equivalent load of relay.

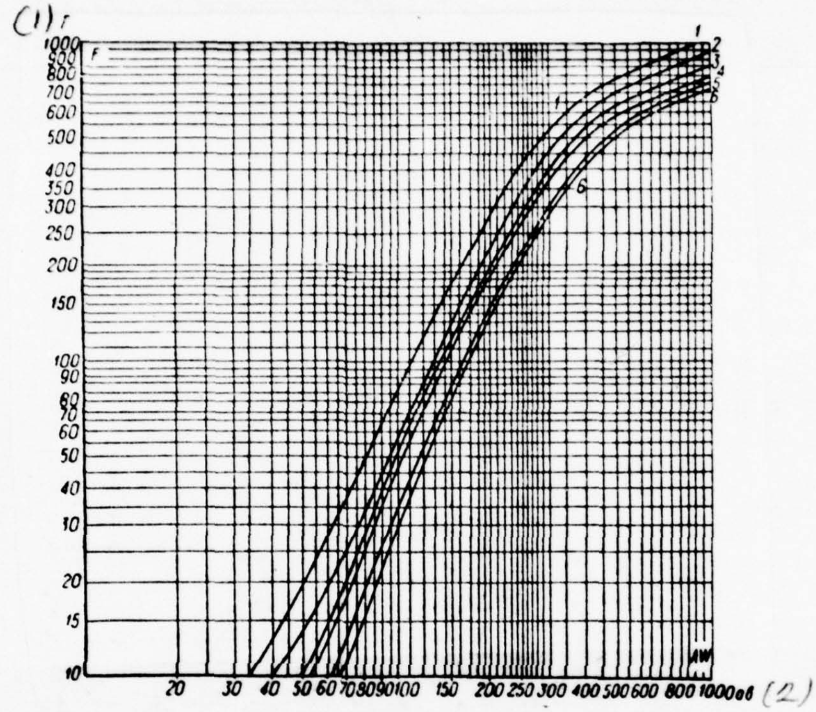


**Fig. 5-3.** Curved for determining ampere-turns of function relays and failure of relay of type RKN. 1 - clearance space $\sigma$ = 0.7 mm; 2 - $\sigma$ = 0.9 mm; 3 - $\sigma$ = 1 mm; 4 - $\sigma$ = 1.1 mm; 5 - $\sigma$ = 1.2 mm; 6 - $\sigma$ = 1.3 mm.
Key: (1) g; (2) AV.

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From the full-load saturation curve, which corresponds to the assigned between iron space (Fig. 5-3), from the

value of the obtained load we find the ampere-turns, necessary for operational provisions of relay with the assigned safety factor.

c) Calculation of the ampere-turns of relay of the type RKMP.

For the calculation of the ampere-turns of function table 5-8 gives equivalent loads for the fundamental contact cell/elements of relay of the type RKMP at the different values of the height/altitude of the plug of loosening.

The common/general/total equivalent load of relay we find, store/adding up equivalent loads for all contact cell/elements of this relay. From curves for determining the ampere-turns of the function of relays of the type RKMP, given in Fig. 5-4, from the value of the obtained load we find ampere-turns necessary for the function of relay. The obtained ampere-turns must be multiplied by that corresponding to the value of the certified/rating safety factor.

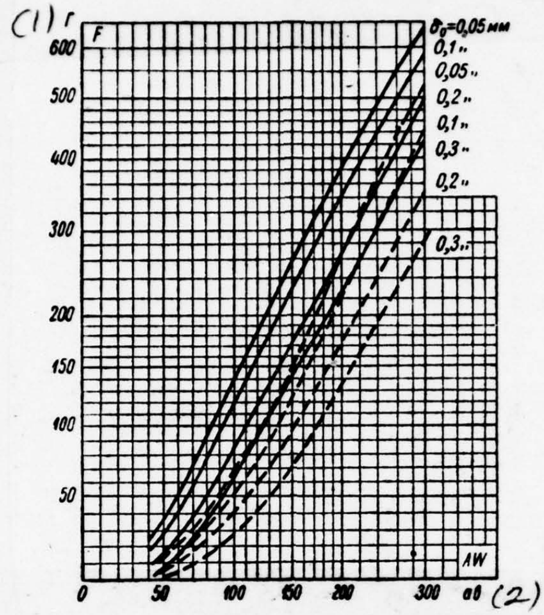


Fig. 5-4. Curved for determining ampere-turns of function relays of type RKMP.

Key: (1) g; (2) AV.

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d) Calculation of the ampere-turns of relay of the type RS-13.

The contact groups of relay of the type RS-13 are

comprised from three of the fundamental contact cell/elements: a) closing/shorting, b) interrupting and c) switching. Furthermore, to the armature of relay of the type RS-13 is always applied the supplementary constant load, created by powerful return spring (by that preventing the fluctuations of armature during vibration).

For the calculation of the ampere-turns of the function of relay of the type RS-13 with different contact loads table 5-9 gives the equivalent loads of function for the return spring of armature and three of fundamental contact cell/elements with the different number of these cell/elements on relay.

Curved for determining the ampere-turns of function relays of the type RS-13 with different cores at the height/altitude of the plugs of loosening 0.1 and 0.2 mm are shown in Fig. 5-5.

The equivalent loads, given table 5-9, gives without taking into account of production tolerances; therefore the ampere-turns, found with the aid of this table, must be multiplied by the appropriate safety factors. The safety factor on ampere-turns for a production certificate is equal to 1.12 and for operating 1.22.

e) Calculation of the ampere-turns of the relay of types RS-52 and RMU.

Table 5-10 and 5-11 gives equivalent loads for the $\delta_0$fundamental contact cell/elements of the relay of the types RS-52 and RMU.

Curved for determining the ampere-turns of the function of these types relays are given in Fig. 5-6 and 5-7.

The ampere-turns of function, obtained with the aid of these curves, must be multiplied by the safety factor, equal for production certificate 1.15 and for operating 1.3.

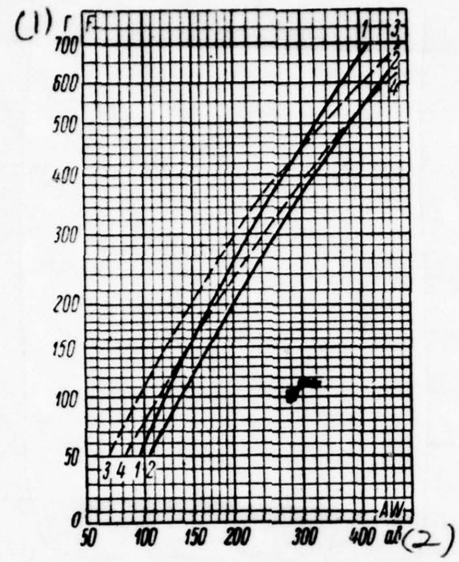


Fig. 5-5. curved for determining ampere-turns of function relays of type RS-13. 1 - without the pole piece $\delta_0$ = 0.1 mm; 2 - the same $\delta_0$ = 0.2 mm; 3 - with the pole piece $\delta_0$ = 0.1 mm; 4 - the same $\delta_0$ = 0.2 mm.

Key: (1) g; (2) AV.

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Table 5-9. Equivalent loads of function fcr relay of the type RS-13 (in grams).

| (1) Число контактных элементов на реле | (2) Контактные элементы | | | (6) Возвратная пружина якоря |
|---|---|---|---|---|
| | (3) Замыкание | (4) Размыкание | (5) Переключение | |
| 1 | 37 | 44 | 48 | 95 |
| 2 | 40 | 50 | 54 | 95 |
| 3 | 43 | 56 | 61 | 95 |
| 4 | 45 | 63 | 68 | 95 |
| 5 | 48 | 68 | 74 | 95 |
| 6 | 50 | 75 | 81 | 95 |

Key: (1). Number of contact cell/elements on relay. (2). Contact cell/elements. (3). Closing/shorting. (4). Interrupting. (5). Switching. (6). Return spring of armature.

Table 5-10. Equivalent loads of function for relay of the type RS-52 (in grams).

| (1) Число контактных элементов | (2) Размыкание | (3) Замыкание | (4) Переключение |
|---|---|---|---|
| 1 | 70 | 100 | 115 |
| 2 | 65 | 70 | 107 |
| 3 | 60 | 68 | 94,2 |
| 4 | 58 | 66,5 | 81,5 |
| 5 | 60 | 56,2 | 74 |
| 6 | 60 | 46 | 66,5 |

Key: (1). Number of contact cell/elements. (2). Interrupting. (3). Closing/shorting. (4). Switching.

Table 5-11. Equivalent loads of function for relay of the type RMU (in grams).

| (1) Число контактных элементов | (2) Размыкание | (3) Замыкание | (4) Переключение | (5) Возвратная пружина якоря |
|---|---|---|---|---|
| 1 | 50 | 35 | 50 | 50 |
| 2 | 52 | 47,5 | 52 | 50 |
| 3 | 45,5 | 50 | 45,5 | 50 |
| 4 | 45,5 | 50 | 45,5 | 50 |

Key: (1). Number of contact cell/elements. (2). Interrupting. (3). Closing/shorting. (4). Switching. (5). Return spring of armature.

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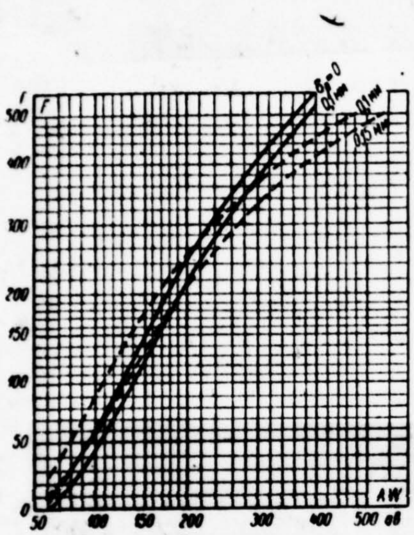


Fig 5.6.

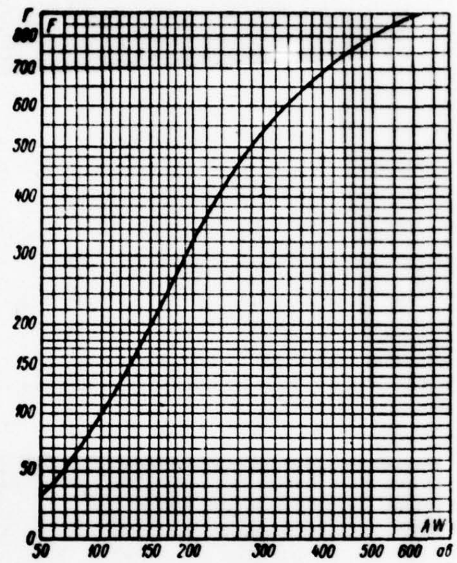


Fig. 5.7.

Fig. 5.6. Curved for determining ampere-turns of function relays of type RS-52.

Fig. 5.7. Curved for determining ampere-turns of function relays of type RMU.

[aB = AV; Г = g]

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5.5. Calculation of the ampere-turns of retention and release/tempering.

The value of the ampere-turns of retention and release/tempering depends on the load of relay and height/altitude of plate or plug of loosening. These ampere-turns can be found from the appropriate tables or the curves of retention (release/tempering) for this type of relay. The load of retention, created by any contact group, easily can be measured, since it is the pressure of this group on the armature, when the latter is completely pullled to core (maximum pressure of group). Therefore the load of the retention of each contact cell/element does not depend on the height/altitude of the plug of loosening and number of cell/elements on relay. The load of release/tempering is nominally equal to the load of retention, but for providing the reliable interrupting (or closing/shorting) of the contacts of relay at release/tempering, the value of the load of release/tempering is accepted a little less.

a) the calculation of the ampere-turns of relay of the type RPN.

For the calculation of the ampere-turns of retention and release/tempering of relay of the type RPN Table 5.12 gives the loads of retention and release/tempering for the fundamental contact groups of this relay, obtained experimentally.

These loads do not in practice depend on the course of armature and quantity of contact groups in packet.

Table gives the average values of the loads of retention and release/tempering taking into account production tolerances.

The curves of the dependences of the ampere-turns of retention on the load of armature with the different thickness of nonmagnetic antistick strips for relay of the type RPN are shown in Fig. 5.8.

Table 5.12. Loads of retention and release/tempering for relay of the type RPN (in grams).

| Номер чертежа группы (1) | Обозначение группы (2) | Удерживание $F_y$ (3) | Отпускание $F_o$ (4) | Номер чертежа группы (1) | Обозначение группы (2) | Удерживание $F_y$ (3) | Отпускание $F_o$ (4) |
|---|---|---|---|---|---|---|---|
| 01 | *a* | 109 | 51 | 27 | *far* | 124 | 52 |
| 02 | *r* | 71 | 30 | 28 | *fra* | 157 | 62 |
| 03 | *u* | 125 | 51 | 29 | *rza* | 154 | 63 |
| 04 | *za* | 165 | 71 | 46 | *aa* | 164 | 68 |
| 05 | *zr* | 117 | 49 | 95 | *afr* | 117 | 49 |
| 07 | *ar* | 152 | 62 | 100 | *gru* | 155 | 71 |
| 10 | *rr* | 130 | 47 | 102 | *gau* | 155 | 68 |
| 11 | *zra* | 125 | 62 | 103 | *gzaa* | 194 | 82 |
| 12 | *ur* | 190 | 81 | 105 | *gua* | 140 | 59 |
| 13 | *au* | 189 | 80 | 106 | *gur* | 140 | 59 |
| 26 | *faa* | 117 | 55 | 107 | *aaa* | 226 | 96 |

Key: (1). Number of drawing of group. (2). Designation of group. (3). Retention. (4). Release/tempering.

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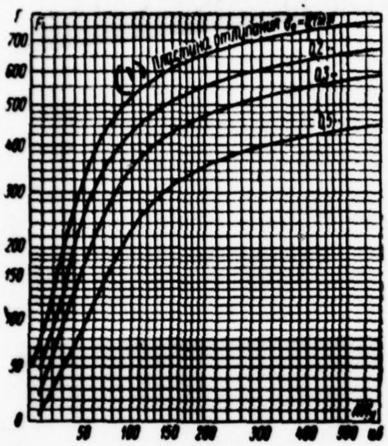


Fig 5.8.

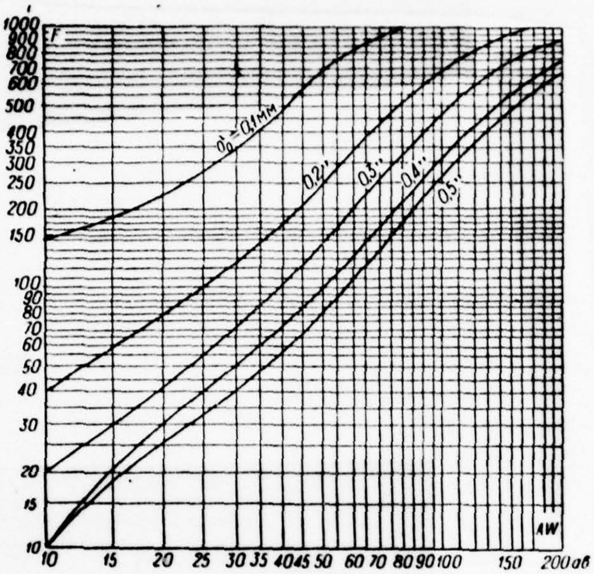


Fig. 5.9.

Fig. 5.8. Curved for determining ampere-turns of release/tempering and retention of relay of type RPN.

Key: (1). Nonmagnetic antistick strip.

Fig. 5.9. Curved for determining ampere-turns of release/tempering and retention of relay of type RKN.

[aB = AV; Г = g]

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b) the calculation of the ampere-turns of relay of the type RKN.

The loads of retention and release/tempering for four fundamental contact cell/elements of relay of the type RKN during the normal adjustment of the latter are given in Table 5.13.

The curves of the dependences of the ampere-turns of retention (release/tempering) on load at the different height/altitude of plugs for relay of the type RKN are given in Fig. 5.9.

c) the calculation of the ampere-turns of the relay of types RKMP, RS-52, RMU and RES14.

Table 5.14 gives the loads of release/tempering for four fundamental contact cell/elements of the relay of types RKMP, RS-52, RMU and RES14.

The curved for determining the ampere-turns of release/tempering relays of the first three types are given in Fig. 5.10, 5.11 and 5.12.

The ampere-turns of release/tempering, obtained with the aid of these curves, must be divided into the appropriate value of the certified/rating value of the safety factor (1.5-1.7 for relay of the type RKMP even 2.0-2.5 for the relay of the types RS-52 and RMU).

**Table 5.13. Loads of retention and release/tempering for relay of the type RKN (in grams).**

| Элемент функция (1) | Размыкание (2) | Замыкание (3) | Переключение (4) | |
|---|---|---|---|---|
| | | | простое (5) | переходное (6) |
| Удержание (7) | 111 | 119 | 167 | 125 |
| Отпускание (8) | 39 | 36 | 58 | 37 |

Key: (1). Cell/element is function. (2). Interrupting. (3). Closing/shorting. (4). Switching. (5). simple. (6). transient. (7). Retention. (8). Release/tempering.

**Table 5.14. Loads of release/tempering for the relay of types RKMP, RS-52, RMU and RES14 (in grams).**

| Контактные элементы (2) | (1) Тип реле | | | |
|---|---|---|---|---|
| | РКМП | РС-52 | РМУ | РЭС14 |
| Размыкание (3) | 77 | 70 | 60 | — |
| Замыкание (4) | 77 | 72 | 73 | 25 |
| Переключение (5) | 106 | 98 | 100 | 25 |
| Возвратная пружина якоря (6) | — | 30 | 80 | 120 |

Key: (1). Type of relay. (2). Contact cell/elements. (3). Interrupting. (4). Closing/shorting. (5). Switching. (6). Return spring of armature.

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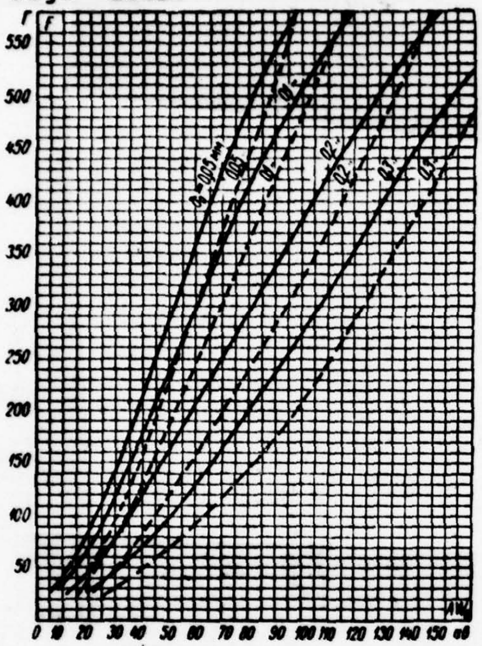


Fig. 5.10.

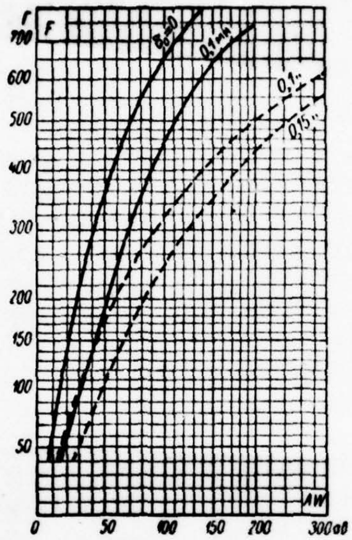


Fig. 5.11

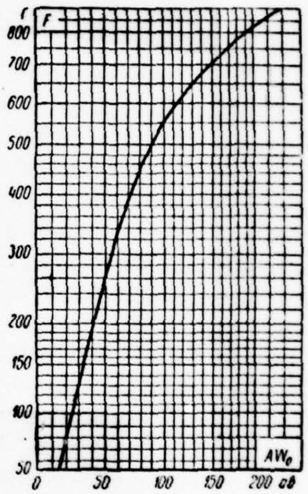


Fig. 5.12.

Fig. 5.10. Curved for determining ampere-turns of release/tempering relays of type RKMP.

Fig. 5.11. Curved for determining ampere-turns of release/tempering relays of type RS-52.

Fig. 5.12. Curved for determining ampere-turns of tempering relays of type RMU.

[aB = AV; Г = g]

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d) the calculation of the ampere-turns of relay of the type RS-13.

The loads of release/tempering for the return spring of armature and three fundamental contact cell/elements of relay of the type RS-13 depending on the number of contact cell/elements on relay are given in Table 5.15.

The curves of the dependences of the ampere-turns of retention on the load of armature at the height/altitude of plugs 0.1 and 0.2 mm for relay of the type RS-13 with different cores are given in Fig. 5.13.

Table 5.15. Loads of release/tempering for relay of the type RS-13 (in grams).

| Число контактных элементов на реле (2) | Контактные элементы (1) | | | Возвратная пружина якоря (6) |
|---|---|---|---|---|
| | Замыкание (3) | Размыкание (4) | Переключение (5) | |
| 1 | 78 | 52 | 119 | 60 |
| 2 | 79 | 59 | 120 | 60 |
| 3 | 80 | 66 | 121 | 60 |
| 4 | 81 | 73 | 123 | 60 |
| 5 | 82 | 78 | 124 | 60 |
| 6 | 83 | 83 | 125 | 60 |

Key: (1). Contact cell/elements. (2). Number of contact cell/elements on relay. (3). Closing/shorting. (4). Interrupting. (5). Switching. (6). Return spring of armature.

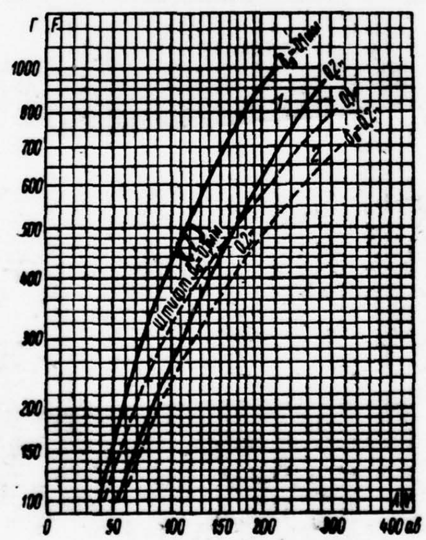


Fig. 5.13. Curved for determining ampere-turns of release/tempering and retention of relay of type RS-13. 1 - without pole piece; 2 - with the pole piece.

Key: (1) Plug. [aB = AV; Г = g]

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The ampere-turns of release/tempering, obtained with the aid of these curves, must be divided into the safety factor, equal for production certificate 1.4 and for operating 1.6.

5.6. Example.

Let us determine the ampere-turns of function, failure, retention and release/tempering for a relay of the type RKN, loaded by two contact groups, which contain one contact cell/element - closing/shorting, two cell/elements - simple switchings even one cell/element - interrupting. Adjustment of relay normal, the course of armature 0.8 mm the height/altitude of the plug of loosening 0.3 mm.

The total number of contact cell/elements on relay is four.

From table 5.6 we find for a plug 0.3 mm the appropriate equivalent loads and store/add up them separately for each function:

for the function

$$F_c = 38 + 2 \cdot 54 + 54 = 200\ g,$$

for the failure

$$F_n = 8 + 2 \cdot 21 + 21 = 71\ g.$$

From the curves of attraction for clearance 0.8 + 0.3 = 1.1 mm (Fig. 5.3) we find the appropriate certified/rating ampere-turns: for function 208 and failure 119 AV.

From Table 5.13 we find the appropriate loads:

for the retention

$$F_y = 119 + 2 \cdot 167 + 111 = 564\ g,$$

for the release/tempering

$$F_o = 36 + 2 \cdot 58 + 39 = 191\ g.$$

On the curves of retention (Fig. 5.9) for a plug 0.3 mm we find the certified/rating ampere-turns: for retention 112 and release/tempering 58 AV.

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Chapter Six.

# CALCULATION OF THE WINDINGS OF RELAYS.

## 6.1. Turn number and winding impedance.

The calculation of the winding of relay consists in the determination of the turn number, diameter of wire and resistor/resistance depending on the structural/design size/dimensions of coil.

In the ideal case the wire on coil can be packed by correct parallel series (turn to turn); however with small diameters and especially with manual winding/coil wire lies down by uneven and loose layers. With the uneven ("wild") winding/coil between turns, there are clearances and therefore on coil is placed less turns than with series winding/coil.

The total sectional area of copper of winding due to

the presence of insulation and the air gaps among wires even with series winding/coil is less than the sectional area of the winding space (window) of coil. The ratio of the sectional area of copper of winding to the section of the winding space, occupied by this winding, is called duty factor:

$$k_3 = \frac{\frac{\pi d^2}{4} w}{lh} = \frac{\pi d^2 w}{4lh}, \qquad (6\text{-}1)$$

where

d - diameter of copper of wire;

w - a turn number,

l - length of winding and

h - a height/altitude of winding/coil.

The value of duty factor depends on the airfoil/profile of the section of wire (circle or rectangle), the thickness of insulation and quality of winding/coil.

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For the wire of round cross-section duty factor

$$k_3 = \frac{\frac{\pi d_1^2}{4}}{d_1^2} \cdot \frac{\frac{\pi d^2}{4}}{\frac{\pi d_1^2}{4}} \cdot k_n = \frac{\pi d^2}{4 d_1^2} k_n, \qquad (6\text{-}2)$$

where $d_1$ is a wire diameter with insulation and

$k_H$ are the coefficient, which considers the inequality of laying (quality of winding/coil).

Coefficient $k_H$ depends on the diameter of wire and qualification of the winder. With small wire diameters - from 0.03 to 0.10 mm - the value of coefficient $k_H$ changes respectively within limits approximately from 0.8 to 0.995.

The turn number of the winding of relay can be expressed by the following formula:

$$w = w_0 lh, \quad (6.3)$$

where $w_0$ - the turn number, which is necessary on 1 mm² of the section of the window of coil. Value $w_0$ depends on the diameter of wire and duty factor. From formulas (6.1), (6.2) and (6.3) we find:

$$w_0 = \frac{4k_3}{\pi d^2} = \frac{k_n}{d_1^2}. \quad (6\text{-}4)$$

Winding impedance of relay in general form

$$r = \rho \frac{L_1}{s}, \qquad (6\text{-}5)$$

where $L_1$ is length of wire in m,

s - section in $mm^2$ and

$\rho$ - the resistivity of the material of wire in $\Omega \cdot mm^2/m$.

For a coil with the core of round cross-section (Fig. 6.1a) the length of wire can be calculated by the following formula:

$$L_1 = w\pi(D_0 + h)\cdot 10^{-3},$$

where $D_0$ - an inner diameter of winding in mm.

Substituting in formula (6.5) instead of $L_1$ and s of their value, we find:

$$r = \frac{4\rho}{d^2} w(D_0 + h)\cdot 10^{-3} = \frac{4\rho}{d^2} w_0 \cdot 10^{-3} lh(D_0 + h).$$

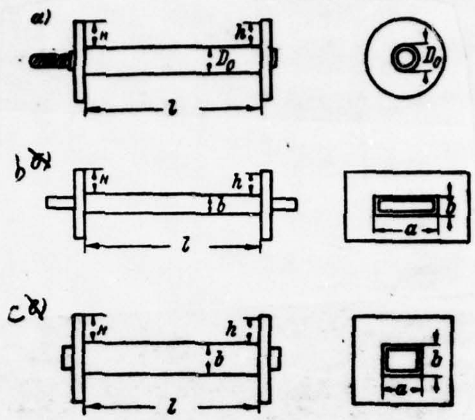


Fig. 6.1. Outlines of coil forms: a) with circular core; b) with flat/plane core; c) by rectangular cross section of core.

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Let us designate:

$$\frac{4\rho}{d^2} w_0 \cdot 10^{-3} = c_0;$$

then winding impedance of relay with circular core will be expressed as follows:

$$r = c_0 lh (D_0 + h). \qquad (6\text{-}6)$$

Substituting in expression for $c_0$ instead of $w_0$ its value, we will obtain:

$$c_0 = \frac{4\rho k_{\text{м}} \cdot 10^{-3}}{d^2 d_1^2} = \frac{0{,}7 k_{\text{м}} \cdot 10^{-4}}{d^2 d_1^2},$$

whence

$$dd_1 = \sqrt{\frac{0{,}7k_{\text{м}} \cdot 10^{-6}}{c_0}}. \qquad (6\text{-}7)$$

The weight of copper of winding without taking into account of the weight of insulation will be, is obvious:

$$Q_{\text{м}} = V\gamma \cdot 10^{-3} = \pi lh\,(D_0 + h)\,k_3\gamma \cdot 10^{-3}, \qquad (6\text{-}8)$$

where V - space of copper in mm³ and $\gamma$ - the specific gravity/weight of copper ($\gamma$ = 8.9 g/cm³).

Winding impedance of relay with flat/plane core (Fig. 6.1b) is equal to:

$$r = c_0 lh\left[\frac{2}{\pi}(a+b) + h\right] = c_0 lh\,(D_0' + h). \qquad (6\text{-}9)$$

For a coil with the rectangular cross section of core (Fig. 6.1c)

$$r = c_0 lh \frac{4}{\pi}\left(\frac{a+b}{2} + h\right) = c_0 lh\,(a + b + 2h), \qquad (6\text{-}10)$$

where a is width of coil form and b - its thickness.

From the given formulas it follows that with the equal sections of core small resistor/resistance will have the winding of relay with circular core.

## 6.2. Dependence of winding impedance on turn number.

Let us multiply numerator and the denominator of the first part of equation (6.6) by w; we obtain:

$$r = \frac{4\rho \cdot 10^{-8}}{d^2 w}(D_0 + h)w^2 = \frac{\pi\rho \cdot 10^{-8}}{lhk_3}(D_0 + h)w^2. \qquad (6\text{-}11)$$

During small changes in the wire diameter, the duty factor is changed insignificantly; therefore with constant/invariable winding space (by replacing one wire of another, differing little in diameter) it is possible to consider winding impedance proportional to the square of turn number, i.e.,

$$r = Cw^2, \qquad (6.12)$$

where C is the averaged resistor/resistance of one turn in the ohms:

$$C = \frac{\pi\rho \cdot 10^{-8}}{lhk_3}(D_0 + h). \qquad (6\text{-}13)$$

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Let us find expression for the height/altitude of the winding of relay depending on its resistor/resistance and turn numbers. Let us rewrite equation (6.11) in the following form:

$$\frac{D_0 + h}{h} = \frac{rlk_3 \cdot 10^8}{\pi\rho w^2}.$$

From last/latter expression we find formula for determining the height/altitude of winding/coil, if are assigned turn number and winding impedance:

$$h = \frac{D_0}{\frac{rlk_3 \cdot 10^8}{\pi\rho w^2} - 1}. \qquad (6\text{-}14)$$

By the value of the duty factor $k_3$ during precomputation it is necessary to be given tentatively and then to more precisely formulate its method successive more precisely formulating of.

In the case when are assigned winding impedance and the wire diameter, the height/altitude of winding can be found from equation (6.6):

$$h=\frac{-c_0lD_0+\sqrt{(c_0lD_0)^2+4c_0lr}}{2c_0l}. \qquad (6\text{-}15)$$

6.3. Double wound and triple-wound coils.

Turn number and the resistor/resistance of the first winding of relay are determined from known formulas (6.3) and (6.7); we have:

$$w_1=w_{01}lh_1 \text{ and } r_1=c_{01}lh_1(D_{01}+h_1).$$

where $h_1$ and $D_{01}$ - height/altitude and the inner diameter of the first winding of relay.

Turn number and the resistor/resistance of the second winding of relay are calculated in a similar manner:

$$w_2 = w_{02} l h_2 \text{ and } r_2 = c_{02} l h_2 (D_{02} + h_2).$$

The inner diameter of the second winding, obviously, will be:

$$D_{02} = D_{01} + 2h_1 + 2\Delta, \tag{6-16}$$

where Δ is thickness of the insulation between windings.

Turn number and the resistor/resistance of the third winding are respectively equal to:

$$w_3 = w_{03} l h_3 \text{ and } r_3 = c_{03} l h_3 (D_{03} + h_3),$$

where

$$D_{03} = D_{02} + 2h_2 + 2\Delta. \tag{6-17}$$

The overall height of all three windings must be not more

than the useful height/altitude of the winding space of coil.

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6.4. Combined windings.

If are assigned turn number and winding impedance, then frequently consecutively with the winding of relay it is necessary to involve supplementary resistor/resistance.

For a decrease in the expenditure of wire instead of the separate supplementary resistor/resistance, the part of the turns of the winding of relay is coiled from constantan wire so that the total quantity of turns and a total resistance of winding would correspond to the assigned conditions. Let us designate turn number and the resistor/resistance of inducing winding, wound from red copper wire, through $w_1$ and $r_1$, but turn number and the resistor/resistance of supplementary winding from the constantan wire by $w_2$ and $r_2$; then

$$w = w_1 + w_2 \quad (6\text{-}18)$$

and

$$r = r_1 + r_2. \quad (6\text{-}19)$$

The resistor/resistances of both windings are respectively equal to:

$$r_1 = \frac{4\rho_1 (D_0 + h_1)}{d_1^2 \cdot 10^3} w_1 \quad (6\text{-}20)$$

and

$$r_2 = \frac{4\rho_2 (D_0 + 2h_1 + h_2)}{d_2^2 \cdot 10^3} w_2, \quad (6\text{-}21)$$

where

$\rho_1$ and $\rho_2$ - the resistivity of the materials of wire;

$h_1$ and $h_2$ - height/altitude of the corresponding windings, and

$d_1$ and $d_2$ - the corresponding wire diameters. wire.

Substituting in expression for r instead of $r_1$ and $r_2$ their value from formulas (6-20) and (6-21), we obtain:

$$r = \frac{4\rho_1 (D_0 + h_1)}{d_1^2 \cdot 10^3} w_1 + \frac{4\rho_2 (D_0 + 2h_1 + h_2)}{d_2^2 \cdot 10^3} w_2.$$

The height/altitude of additional winding from constantan $h_2$ is usually small in comparison with $(D_0 + h_1)$, and therefore it is possible to write:

$$D_0 + h_1 \approx D_0 + h \quad \text{and} \quad D_0 + 2h_1 + h_2 \approx D_0 + 2h.$$

If both windings are wound of the wire of just one

diameter, then, by substituting for $w_2$ its value from expression (6.18), we will obtain:

$$r = \frac{4}{d^2 \cdot 10^6} \{[(\rho_1 - \rho_2)(D_0 + h_1) - \rho_2 h] w_1 + \rho_2 (D_0 + 2h_1) w\}.$$

From this we obtain formula for determining the turn number of inducing winding from the copper wire:

$$w_1 = \frac{4\rho_2 w (D_0 + 2h) - r d^2 \cdot 10^6}{4[\rho_2 (D_0 + 2h) - \rho_1 (D_0 + h)]}. \qquad (6\text{-}22)$$

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The height/altitude of inducing winding and its resistor/resistance we determine with the aid of (6.3) and (6.7). The turn number of the supplementary winding $w_2$ we find from formula (6.18).

Supplementary winding usually has very small turn number, less than one layer (series); therefore independent of turn number the mean diameter of supplementary winding will be equal to:

$$D_{02} = D_0 + 2h_1 + 2\Delta + d'_2, \qquad (6.23)$$

where $\Delta$ is thickness of the cable paper, laid between both windings, and $d'_2$ - a outside diameter of constantan wire (with insulation).

For the computation of the resistor/resistance of

supplementary winding, formula (6.6) is inconvenient, since this winding frequently has one incomplete layer of wire: therefore the resistor/resistance of supplementary winding one should calculate according to the common/general/total formula:

$$r_2 = \frac{4\rho_2}{d_2^2} D_{02} w_2 \cdot 10^{-2}. \qquad (6\text{-}24)$$

The turn number of supplementary winding is a small difference in two large values and therefore it cannot be found with sufficient accuracy. Therefore the turn number of supplementary winding is better to determine from (6.24), whence

$$w_2 = \frac{r_2 d_2^2 \cdot 10^2}{4\rho_2 D_{02}}, \qquad (6\text{-}25)$$

where $r_2$ is resistor/resistance of the supplementary winding whose value is determined from formula (6.19).

## 6.5. Selection of the wire diameter.

If turn number or winding impedance is assigned, then from formulas (6.3) and (6.7) it is possible to find:

$$w_0 = \frac{w}{lh} \text{ or } c_0 = \frac{r}{lh\,(D_0 + h)}.$$

The selection of the required wire diameter can be produced on with given Table 6.1 and 6.2 for the calculation of windings.

In these tables are given values $w_0$, $c_0$ and $k_3$ for red copper wire with enamel and silk insulation by diameter from 0.05 to 1.0 mm at temperature of +15°C. When selecting of the wire diameter, it is necessary to largely round off the obtained value $w_0$ or $c_0$ to the value, which corresponds to the nearest nominal (standard) size/dimension of wire; in such cases the actual height/altitude of winding h' will not be equal to h. The actual height/altitude of winding can be calculated with the aid of value $w'_0$, undertaken from table with respect to the selected wire diameter:

$$h' = \frac{w}{l w'_0}. \quad (6.26)$$

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Table 6.1a. Wire of red copper with enamel insulation of the brand PEL.

| d, мм | $d_1$, мм | $w_0$ | $c_0$ | $k_3$ | r, ом/м (1) | g, г/м (2) | $g_1$, г/ом (3) | Относительная стоимость (4) |
|---|---|---|---|---|---|---|---|---|
| 0,02 | 0,033 | 690 | 120,05 | 0,218 | 55,7 | — | — | — |
| 0,03 | 0,040 | 500 | 38,80 | 0,352 | 24,76 | 0,012 | 0,00049 | 34,5 |
| 0,04 | 0,050 | 327 | 14,30 | 0,410 | 13,93 | 0,015 | 0,00108 | 7,12 |
| 0,05 | 0,065 | 200 | 5,57 | 0,390 | 8,92 | 0,019 | 0,00209 | 2,32 |
| 0,06 | 0,075 | 145 | 2,50 | 0,420 | 6,19 | 0,027 | 0,00429 | 2,18 |
| 0,07 | 0,085 | 122 | 1,74 | 0,468 | 4,55 | 0,036 | 0,0079 | 1,66 |
| 0,08 | 0,095 | 99 | 1,08 | 0,497 | 3,48 | 0,047 | 0,0134 | 1,42 |
| 0,09 | 0,105 | 82,2 | 0,710 | 0,522 | 2,75 | 0,059 | 0,0214 | 1,21 |
| 0,10 | 0,120 | 69,1 | 0,484 | 0,543 | 2,23 | 0,073 | 0,0327 | 1,00 |
| 0,11 | 0,130 | 59,0 | 0,342 | 0,561 | 1,84 | 0,088 | 0,0478 | 0,93 |
| 0,12 | 0,140 | 51,0 | 0,248 | 0,576 | 1,55 | 0,104 | 0,0675 | 0,87 |
| 0,13 | 0,150 | 44,4 | 0,185 | 0,589 | 1,32 | 0,122 | 0,093 | 0,785 |
| 0,14 | 0,160 | 39,1 | 0,140 | 0,601 | 1,14 | 0,141 | 0,125 | 0,742 |
| 0,15 | 0,170 | 34,5 | 0,108 | 0,611 | 0,99 | 0,162 | 0,1638 | 0,677 |
| 0,16 | 0,180 | 30,7 | 0,0839 | 0,617 | 0,87 | 0,184 | 0,212 | 0,660 |
| 0,17 | 0,190 | 27,4 | 0,0668 | 0,621 | 0,772 | 0,208 | 0,269 | 0,637 |
| 0,18 | 0,200 | 24,5 | 0,0531 | 0,624 | 0,688 | 0,233 | 0,338 | 0,625 |
| 0,19 | 0,210 | 22,1 | 0,0430 | 0,626 | 0,616 | 0,259 | 0,419 | 0,608 |
| 0,20 | 0,225 | 20,0 | 0,0350 | 0,628 | 0,557 | 0,287 | 0,519 | 0,592 |
| 0,21 | 0,235 | 18,2 | 0,0290 | 0,630 | 0,506 | 0,316 | 0,629 | 0,573 |
| 0,23 | 0,255 | 15,25 | 0,0202 | 0,634 | 0,421 | 0,378 | 0,901 | 0,540 |
| 0,25 | 0,275 | 12,96 | 0,0145 | 0,636 | 0,357 | 0,446 | 1,26 | 0,505 |
| 0,27 | 0,305 | 10,76 | 0,01033 | 0,639 | 0,310 | 0,522 | 1,72 | 0,498 |
| 0,29 | 0,325 | 9,46 | 0,00787 | 0,642 | 0,265 | 0,601 | 2,28 | 0,490 |
| 0,31 | 0,350 | 8,53 | 0,00623 | 0,644 | 0,236 | 0,689 | 2,98 | 0,485 |
| 0,33 | 0,370 | 7,56 | 0,00486 | 0,646 | 0,205 | 0,780 | 3,84 | 0,477 |
| 0,35 | 0,390 | 6,74 | 0,00386 | 0,648 | 0,182 | 0,876 | 4,85 | 0,470 |
| 0,38 | 0,420 | 5,73 | 0,00278 | 0,650 | 0,154 | 1,03 | 6,7 | 0,460 |
| 0,41 | 0,450 | 4,95 | 0,00206 | 0,653 | 0,132 | 1,202 | 9,4 | 0,451 |
| 0,44 | 0,485 | 4,25 | 0,00154 | 0,655 | 0,115 | 1,382 | 12,1 | 0,442 |
| 0,47 | 0,515 | 3,77 | 0,00120 | 0,657 | 0,101 | 1,574 | 15,7 | 0,434 |
| 0,49 | 0,535 | 3,49 | 0,001015 | 0,658 | 0,0926 | 1,713 | 18,5 | 0,426 |
| 0,51 | 0,56 | 3,23 | 0,000871 | 0,660 | 0,086 | 1,856 | 21,8 | 0,424 |
| 0,55 | 0,60 | 2,79 | 0,000647 | 0,663 | 0,074 | 2,15 | 26,3 | 0,415 |
| 0,59 | 0,64 | 2,44 | 0,000491 | 0,666 | 0,0642 | 2,47 | 38,5 | 0,408 |
| 0,64 | 0,69 | 2,08 | 0,000356 | 0,670 | 0,0544 | 2,91 | 53,5 | 0,401 |
| 0,69 | 0,74 | 1,80 | 0,000265 | 0,673 | 0,0470 | 3,42 | 72,9 | 0,397 |
| 0,74 | 0,80 | 1,57 | 0,000201 | 0,676 | 0,0407 | 3,89 | 95,6 | 0,394 |
| 0,80 | 0,86 | 1,35 | 0,000148 | 0,680 | 0,0348 | 4,49 | 129 | 0,389 |
| 0,93 | 0,99 | 1,02 | 0,0000825 | 0,687 | 0,0258 | 6,12 | 237 | 0,380 |
| 1,00 | 1,07 | 0,881 | 0,0000618 | 0,692 | 0,0223 | 7,07 | 314 | 0,375 |

Key: (1). Ω/m. (2) V/m. (3) g/ohm. (4). Relative cost/value.

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Table 6.1b. Wire of rod copper with enamel insulation.

| d, мм | (1) Марки ПЭВ-1 | | | | (1) Марки ПЭВ-2 | | | | (1) Марки ПЭТВ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_1$, мм | $w_0$ | $c_0$ | $k_0$ | $d_1$, мм | $w_0$ | $c_0$ | $k_0$ | $d_1$, мм | $w_0$ | $c_0$ | $k_0$ |
| 0,03 | — | — | — | — | — | — | — | — | 0,045 | 400 | 30,8 | 0,278 |
| 0,04 | — | — | — | — | — | — | — | — | 0,055 | 268 | 11,9 | 0,342 |
| 0,05 | — | — | — | — | — | — | — | — | 0,065 | 197 | 5,54 | 0,390 |
| 0,06 | 0,085 | 113 | 2,200 | 0,319 | 0,09 | 100,5 | 1,955 | 0,284 | 0,085 | 120 | 2,32 | 0,336 |
| 0,07 | 0,095 | 97,6 | 1,392 | 0,376 | 0,10 | 88,2 | 1,173 | 0,339 | 0,105 | 82 | 1,142 | 0,307 |
| 0,08 | 0,105 | 81,0 | 0,887 | 0,408 | 0,11 | 73,3 | 0,803 | 0,370 | 0,115 | 67,4 | 0,738 | 0,340 |
| 0,09 | 0,115 | 68,6 | 0,598 | 0,436 | 0,12 | 62,9 | 0,543 | 0,399 | 0,125 | 57,9 | 0,501 | 0,369 |
| 0,10 | 0,125 | 63,8 | 0,447 | 0,501 | 0,13 | 58,9 | 0,412 | 0,462 | 0,14 | 50,8 | 0,356 | 0,398 |
| 0,11 | 0,135 | 54,9 | 0,317 | 0,520 | — | — | — | — | — | — | — | — |
| 0,12 | 0,145 | 47,6 | 0,231 | 0,538 | 0,15 | 44,4 | 0,308 | 0,501 | 0,16 | 39,0 | 0,1895 | 0,442 |
| 0,14 | 0,165 | 36,7 | 0,131 | 0,565 | 0,17 | 34,5 | 0,1232 | 0,529 | — | — | — | — |
| 0,15 | 0,18 | 30,9 | 0,098 | 0,545 | 0,19 | 27,7 | 0,086 | 0,490 | 0,19 | 27,7 | 0,0864 | 0,489 |
| 0,16 | 0,19 | 27,7 | 0,0759 | 0,571 | 0,20 | 25,0 | 0,0684 | 0,502 | 0,20 | 25,0 | 0,0684 | 0,502 |
| 0,18 | 0,21 | 22,7 | 0,0491 | 0,578 | 0,22 | 20,65 | 0,0446 | 0,526 | 0,22 | 20,6 | 0,0446 | 0,526 |
| 0,20 | 0,23 | 18,9 | 0,0331 | 0,594 | 0,24 | 17,39 | 0,0304 | 0,546 | 0,24 | 17,38 | 0,03040 | 0,546 |
| 0,23 | 0,27 | 13,7 | 0,0182 | 0,571 | 0,28 | 12,76 | 0,01688 | 0,530 | 0,28 | 12,75 | 0,01683 | 0,530 |
| 0,25 | 0,29 | 11,9 | 0,0138 | 0,584 | 0,30 | 11,11 | 0,01246 | 0,545 | 0,30 | 11,1 | 0,01243 | 0,545 |
| 0,27 | 0,31 | 10,4 | 0,00999 | 0,597 | 0,32 | 9,75 | 0,00935 | 0,557 | 0,33 | 9,20 | 0,00884 | 0,524 |
| 0,29 | 0,33 | 9,2 | 0,00768 | 0,607 | 0,34 | 8,65 | 0,00721 | 0,573 | — | — | — | — |
| 0,31 | 0,35 | 8,17 | 0,00595 | 0,616 | 0,36 | 7,72 | 0,00562 | 5,588 | 0,37 | 7,32 | 0,00534 | 0,550 |
| 0,33 | 0,37 | 7,32 | 0,00470 | 0,625 | 0,38 | 6,93 | 0,00445 | 0,593 | — | — | — | — |
| 0,35 | 0,39 | 6,57 | 0,00375 | 0,632 | 0,41 | 5,96 | 0,00341 | 0,573 | 0,41 | 5,96 | 0,00341 | 0,573 |
| 0,38 | 0,42 | 5,68 | 0,00276 | 0,643 | 0,44 | 5,17 | 0,00251 | 0,586 | 0,44 | 5,17 | 0,00251 | 0,586 |
| 0,41 | 0,45 | 4,94 | 0,00205 | 0,653 | 0,47 | 4,53 | 0,00188 | 0,597 | 0,47 | 4,54 | 0,00189 | 0,597 |
| 0,44 | 0,48 | 4,34 | 0,00157 | 0,660 | 0,50 | 4,00 | 0,00150 | 0,608 | 0,51 | 3,85 | 0,00139 | 0,584 |
| 0,47 | 0,51 | 3,85 | 0,00122 | 0,667 | 0,53 | 3,57 | 0,001135 | 0,618 | 0,54 | 3,44 | 0,00109 | 0,596 |
| 0,49 | 0,53 | 3,56 | 0,001039 | 0,668 | 0,55 | 3,31 | 0,000965 | 0,623 | — | — | — | — |
| 0,51 | 0,56 | 3,19 | 0,000880 | 0,653 | 0,58 | 2,97 | 0,0080 | 0,607 | 0,58 | 2,98 | 0,0008 | 0,607 |
| 0,53 | 0,58 | 2,98 | 0,000743 | 0,656 | 0,60 | 2,78 | 0,000692 | 0,613 | | | | |
| 0,55 | 0,60 | 2,78 | 0,000644 | 0,659 | 0,62 | 2,60 | 0,000604 | 0,617 | | | | |
| 0,59 | 0,64 | 2,45 | 0,000493 | 0,666 | 0,66 | 2,30 | 0,000463 | 0,627 | | | | |
| 0,64 | 0,69 | 2,10 | 0,000359 | 0,675 | 0,72 | 1,93 | 0,000330 | 0,620 | | | | |
| 0,69 | 0,74 | 1,83 | 0,000269 | 0,681 | 0,77 | 1,63 | 0,000249 | 0,632 | | | | |
| 0,74 | 0,80 | 1,56 | 0,000200 | 0,673 | 0,83 | 1,45 | 0,000185 | 0,625 | | | | |
| 0,80 | 0,86 | 1,35 | 0,000148 | 0,678 | 0,89 | 1,26 | 0,000138 | 0,636 | | | | |
| 0,86 | 0,92 | 1,18 | 0,000112 | 0,687 | 0,95 | 1,10 | 0,000105 | 0,646 | | | | |
| 0,93 | 0,99 | 1,02 | 0,000083 | 0,693 | 1,02 | 0,96 | 0,000078 | 0,653 | | | | |
| 1,00 | 1,08 | 0,860 | 0,000060 | 0,673 | 1,11 | 0,812 | 0,000057 | 0,638 | | | | |
| 1,08 | 1,16 | 0,744 | 0,000044 | 0,678 | 1,19 | 0,707 | 0,000042 | 0,645 | | | | |
| 1,16 | 1,24 | 0,652 | 0,000034 | 0,687 | 1,27 | 0,620 | 0,000032 | 0,656 | | | | |
| 1,25 | 1,33 | 0,565 | 0,000025 | 0,692 | 1,36 | 0,542 | 0,000024 | 0,663 | | | | |

Key: (1) Brand.

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Table 6.2. Wire copper of the brand PELShO.

| Номинальный диаметр d, мм (1) | Расчетный наружный диаметр $d_1$, мм (2) | $w_0$ | $c_0$ | $k_3$ | Сопротивление 1 м, r, ом (3) | (4) Вес 1 м g, г |
|---|---|---|---|---|---|---|
| 0,05 | 0,13 | 69,1 | 1,94 | 0,135 | 8,95 | 0,033 |
| 0,06 | 0,14 | 59,0 | 1,15 | 0,167 | 6,19 | 0,042 |
| 0,07 | 0,15 | 51,0 | 0,73 | 0,196 | 4,55 | 0,053 |
| 0,08 | 0,16 | 44,4 | 0,488 | 0,222 | 3,48 | 0,065 |
| 0,09 | 0,17 | 39,1 | 0,338 | 0,237 | 2,75 | 0,079 |
| 0,10 | 0,18 | 32,7 | 0,230 | 0,257 | 2,23 | 0,093 |
| 0,12 | 0,20 | 26,3 | 0,128 | 0,297 | 1,55 | 0,127 |
| 0,13 | 0,21 | 23,8 | 0,0988 | 0,316 | 1,32 | 0,147 |
| 0,14 | 0,22 | 21,6 | 0,0774 | 0,332 | 1,14 | 0,167 |
| 0,15 | 0,23 | 20,0 | 0,0623 | 0,354 | 0,99 | 0,19 |
| 0,16 | 0,24 | 18,2 | 0,0498 | 0,366 | 0,87 | 0,21 |
| 0,17 | 0,25 | 16,6 | 0,0403 | 0,377 | 0,772 | 0,24 |
| 0,18 | 0,255 | 15,4 | 0,0329 | 0,388 | 0,685 | 0,26 |
| 0,20 | 0,290 | 11,9 | 0,02085 | 0,374 | 0,557 | 0,32 |
| 0,21 | 0,300 | 11,1 | 0,01767 | 0,384 | 0,506 | 0,36 |
| 0,23 | 0,320 | 9,79 | 0,01300 | 0,406 | 0,421 | 0,42 |
| 0,25 | 0,340 | 8,65 | 0,00972 | 0,425 | 0,357 | 0,49 |
| 0,27 | 0,370 | 7,56 | 0,00729 | 0,433 | 0,310 | 0,57 |
| 0,29 | 0,390 | 6,74 | 0,00563 | 0,444 | 0,265 | 0,66 |
| 0,31 | 0,415 | 5,82 | 0,00425 | 0,439 | 0,236 | 0,76 |
| 0,33 | 0,435 | 5,30 | 0,00343 | 0,452 | 0,205 | 0,84 |
| 0,35 | 0,455 | 4,83 | 0,00277 | 0,464 | 0,182 | 0,95 |
| 0,38 | 0,485 | 4,31 | 0,00210 | 0,490 | 0,154 | 1,10 |
| 0,41 | 0,520 | 3,69 | 0,00154 | 0,487 | 0,132 | 1,27 |
| 0,44 | 0,550 | 3,30 | 0,001197 | 0,502 | 0,115 | 1,46 |
| 0,47 | 0,580 | 3,00 | 0,000954 | 0,520 | 0,101 | 1,66 |
| 0,51 | 0,625 | 2,56 | 0,000691 | 0,522 | 0,086 | 1,95 |
| 0,55 | 0,665 | 2,27 | 0,000527 | 0,538 | 0,074 | 2,25 |
| 0,59 | 0,705 | 2,01 | 0,000406 | 0,549 | 0,0642 | 2,58 |
| 0,64 | 0,755 | 1,76 | 0,000301 | 0,565 | 0,0544 | 3,02 |
| 0,69 | 0,805 | 1,55 | 0,000229 | 0,579 | 0,0470 | 3,49 |
| 0,74 | 0,865 | 1,33 | 0,000170 | 0,572 | 0,0407 | 4,02 |
| 0,80 | 0,925 | 1,17 | 0,000128 | 0,589 | 0,0348 | 4,68 |
| 0,86 | 0,985 | 1,03 | 0,000098 | 0,598 | 0,0301 | 5,39 |
| 0,93 | 1,055 | 0,90 | 0,000073 | 0,611 | 0,0258 | 6,29 |
| 1,00 | 1,135 | 0,777 | 0,0000545 | 0,610 | 0,0223 | 7,28 |

Key: (1). Nominal diameter. (2). Calculated outside diameter. (3). Resistor/resistance 1 m r, ohm. (4). Weight 1 m g, g.

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Table 6.3. Wire constantan of the brand PEShOK ($\rho$ = 0.465 $\Omega \cdot mm^2/m$).

| (1) Номинальный диаметр d, мм | (2) Максимальный наружный диаметр $d_1$, мм | $w_0$ | $c_0$ | $k_3$ | (3) Сопротивление 1 м r, ом | (4) Вес 1 м g, г |
|---|---|---|---|---|---|---|
| 0,03 | 0,09 | 109 | 233 | 0,077 | 658 | — |
| 0,05 | 0,13 | 54,9 | 42,1 | 0,107 | 237 | 0,034 |
| 0,06 | 0,14 | 47,6 | 25,4 | 0,135 | 164,5 | 0,043 |
| 0,07 | 0,15 | 41,7 | 16,4 | 0,161 | 120,8 | 0,054 |
| 0,08 | 0,16 | 36,8 | 11,0 | 0,184 | 92,5 | 0,066 |
| 0,09 | 0,17 | 32,7 | 7,78 | 0,198 | 73,1 | 0,800 |
| 0,10 | 0,185 | 25,0 | 4,80 | 0,196 | 59,2 | 0,920 |
| 0,12 | 0,205 | 20,6 | 2,74 | 0,232 | 41,1 | 0,126 |
| 0,15 | 0,235 | 16,0 | 1,37 | 0,283 | 26,3 | 0,187 |
| 0,18 | 0,265 | 12,3 | 0,728 | 0,314 | 18,27 | 0,261 |
| 0,20 | 0,30 | 10,0 | 0,480 | 0,314 | 14,8 | 0,315 |
| 0,25 | 0,35 | 6,90 | 0,212 | 0,339 | 9,47 | 0,491 |
| 0,30 | 0,41 | 5,40 | 0,1152 | 0,382 | 6,58 | 0,748 |
| 0,35 | 0,46 | 4,17 | 0,0656 | 0,401 | 4,88 | 0,947 |
| 0,40 | 0,51 | 3,44 | 0,0413 | 0,434 | 3,7 | 1,269 |
| 0,45 | 0,57 | 2,78 | 0,0264 | 0,442 | 2,92 | 1,527 |
| 0,50 | 0,62 | 2,36 | 0,0181 | 0,462 | 2,37 | 1,872 |
| 0,60 | 0,72 | 1,73 | 0,00925 | 0,490 | 1,645 | 2,667 |
| 0,70 | 0,83 | 1,32 | 0,00517 | 0,509 | 1,208 | 3,033 |
| 0,80 | 0,93 | 1,06 | 0,00318 | 0,533 | 0,925 | 4,684 |
| 1,00 | 1,14 | 0,707 | 0,00134 | 0,555 | 0,592 | 8,283 |

Key: (1). Nominal diameter d, mm. (2). Maximum outside diameter $d_1$, mm. (3). Resistor/resistance 1 m r, ohm. (4). Weight 1 m g, g.

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Table 6.4. Size/dimensions of the winding space of the coils of relay.

| (2) Наименование реле | (1) Размеры обмотки | | | | | |
|---|---|---|---|---|---|---|
| | (3) Внутренний диаметр $D_0$, мм | (4) Длина $l$, мм | (5) Высота $h$, мм | (6) Объем обмоточного пространства $\Omega$, мм³ | (7а) Высота щечки катушки $H$, мм | (7б) $C_m$, ом |
| (8) Реле типа РКН | | | | | | |
| а) Нормальное (9) | 9,5 | 59,1 | 6,7 | 396 | 7,6 | $2{,}25 \cdot 10^{-6}$ |
| б) Замедленное $l_в = 12{,}8$ мм | 9,5 | 45,5 | 6,7 | 305 | 7,6 | $2{,}92 \cdot 10^{-6}$ |
| в) (10) » $l_в = 25{,}5$ мм | 9,5 | 32,8 | 6,7 | 220 | 7,6 | $4{,}05 \cdot 10^{-6}$ |
| г) » $l_в = 38$ мм | 9,5 | 20,3 | 6,7 | 136 | 7,6 | $6{,}55 \cdot 10^{-6}$ |
| д) » $h = 4$ мм | 17,5 | 59,1 | 2,7 | 160 | 7,6 | $6{,}97 \cdot 10^{-6}$ |
| е) Питающее (11) | 12,3 | 59,1 | 5,3 | 313 | 6,2 | $3{,}1 \cdot 10^{-6}$ |
| (8) Реле типа РКМ-1 | | | | | | |
| а) Нормальное (9) | 7,5 | 47,5 | 4,2 | 200 | 5,0 | $3{,}24 \cdot 10^{-6}$ |
| б) Замедленное $h = 1$ мм | 9,5 | 47,5 | 3,2 | 152 | 3,7 | $4{,}60 \cdot 10^{-6}$ |
| в) (10) » $h = 2$ мм | 11,5 | 47,5 | 2,2 | 105 | 2,7 | $7{,}18 \cdot 10^{-6}$ |
| (8) Реле типа РКМП | | | | | | |
| а) Нормальное (9) | 9,8 | 46 | 6,0 | 276 | 6,7 | $3{,}15 \cdot 10^{-6}$ |
| б) Замедленное $h = 2$ мм | 13,8 | 46 | 4,0 | 184 | 6,7 | $5{,}32 \cdot 10^{-6}$ |
| в) (10) » $h = 3$ мм | 15,8 | 46 | 3,0 | 138 | 6,7 | $7{,}50 \cdot 10^{-6}$ |
| г) » $h = 4$ мм | 17,8 | 46 | 2,0 | 92 | 6,7 | $11{,}85 \cdot 10^{-6}$ |
| Реле типа РПН | | | | | | |
| а) Нормальное | 9,6[1] | 50 | 6,6 | 330 | 7,2 | $2{,}7 \cdot 10^{-6}$ |
| б) Замедленное $h = 1$ мм | 11,6 | 50 | 5,6 | 280 | 6,2 | $3{,}4 \cdot 10^{-6}$ |
| в) (10) » $h = 2$ мм | 13,6 | 50 | 4,6 | 230 | 5,2 | $4{,}35 \cdot 10^{-6}$ |
| г) » $h = 3$ мм | 15,6 | 50 | 3,6 | 180 | 4,2 | $5{,}86 \cdot 10^{-6}$ |
| (8) Реле типа РЭС14 | | | | | | |
| а) Нормальное (9) | 8,8 | 54,5 | 5,5 | 300 | 6,5 | $2{,}68 \cdot 10^{-6}$ |
| б) Замедленное $h = 1{,}25$ мм | 10,5 | 54 | 4,5 | 243 | 5,25 | $3{,}39 \cdot 10^{-6}$ |
| в) (10) » $h = 2{,}0$ мм | 12,0 | 54 | 3,75 | 203 | 4,5 | $4{,}26 \cdot 10^{-6}$ |
| г) » $h = 2{,}75$ мм | 13,5 | 54 | 3,0 | 162 | 3,75 | $5{,}60 \cdot 10^{-6}$ |
| д) Питающее (11) | 10,0 | 54 | 5,0 | 270 | 5,75 | $3{,}06 \cdot 10^{-6}$ |
| Реле типа ТКЕ21ПД | 5,5 | 13,5 | 4,0 | 54 | — | $9{,}67 \cdot 10^{-6}$ |
| » (8) » ТКЕ52ПД | 7,0 | 19,0 | 4,0 | 76 | — | $7{,}95 \cdot 10^{-6}$ |
| » » ТКД12ПД | 9,5 | 21,5 | 7,5 | 161 | — | $5{,}8 \cdot 10^{-6}$ |
| » » РС-13 | 7,6 | 24 | 3,7 | 124 | 4,2 | $[illegible]{,}93 \cdot 10^{-6}$ |
| » » РС-52 | 8,8 | 24,5 | 3,5 | 121 | 4,1 | $[illegible]{,}6 \cdot 10^{-6}$ |
| (8) Реле типа РМУ | | | | | | |
| а) Нормальное (9) | 8,8 | 28 | 6,9 | 1109 | 4,8 | $[illegible]{,}4 \cdot 10^{-6}$ |
| б) Замедленное $l_в = 17$ мм | 8,8 | 11 | 3,9 | 42,9 | 4,6 | $16{,}3 \cdot 10^{-6}$ |
| Реле типа РДЧГ | 5,5 | 2 × 30,6 | 4,0 | 2 × 122 | 4,5 | $2{,}14 \cdot 10^{-6}$ |
| » (8) » РЭС7 | 8,0 | 20 | 4,3 | 85,4 | — | $[illegible]{,}9 \cdot 10^{-6}$ |
| » » РЭС8 | 12,0 | 25 | 5,6 | 84 | 7,2 | $11{,}5 \cdot 10^{-6}$ |
| » » РЭС6 | 5,5 | 18,5 | 3,0 | 65,5 | 3,55 | $8{,}43 \cdot 10^{-6}$ |
| » » РЭС22 | 4,93[3] | 17,6 | 3,35 | 59,0 | 3,75 | $7{,}7 \cdot 10^{-6}$ |
| » » РЭС9 | 3,7 | 2 × 11 | 1,7 | 2 × 18,7 | 2,15 | $7{,}95 \cdot 10^{-6}$ |
| » » РЭС10 | 3,5 | 8,9 | 2,0 | 17,8 | 2,55 | $17{,}0 \cdot 10^{-6}$ |
| » » РЭС15 | 3,5[3] | 7,6 | 1,6 | 12,1 | 2,25 | $23{,}2 \cdot 10^{-6}$ |
| Реле типа РПС20 | 3,8 | 2 × 90,6 | 2,0 | 21,2 | — | $7{,}5 \cdot 10^{-6}$ |
| » (8) » РЭН17 | 10,1 | 59,1 | 6,4 | 378 | 7,1 | $2{,}4 \cdot 10^{-6}$ |
| » » РЭН18 | 11,0 | 61,4 | 6,05 | 372 | 7,1 | $2{,}52 \cdot 10^{-6}$ |
| » » РЭН19 | 10,0 | 52,7 | 6,4 | 337 | 7,1 | $2{,}64 \cdot 10^{-6}$ |
| » » РЭН20 | 12,1 | 27,0 | 7,4 | 200 | 8,1 | $5{,}35 \cdot 10^{-6}$ |
| » » РЭН21 | 10,0 | 22,5 | 6,5 | 146 | 7,6 | $6{,}22 \cdot 10^{-6}$ |
| » » МКУ-48 | 19,7[4] | 21,0 | 7,0 | 147 | 8,75 | $10{,}0 \cdot 10^{-6}$ |
| » » РПНВ | 10,2[5] | 50,0 | 6,2 | 310 | 7,2 | $2{,}9 \cdot 10^{-6}$ |
| » » КДР1 | 14,7 | 66,5 | 7,0 | 465 | 7,5 | $2{,}56 \cdot 10^{-6}$ |

Key: (1). Size/dimensions of winding. (2). name of relay. (3). Internalizations diameters. (4). Length. (5) height/altitude. (6). Section of winding space. (7a). Height/altitude of the jaw of coil. (7b). ohm. (8). Relays of the type. (9). Normal. (10). Retarded. (11). Feeding.

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FOOTNOTE [1]. Diameter, equivalent on the perimeter: a = 10.75 mm, b = 4.3 mm.

[2]. Diameter, equivalent on perimeter: a = 5.12 mm, b = 2.62 mm.

[3]. Diameter, equivalent on perimeter: a = 4.3 mm, b = 1.22 mm.

[4]. Diameter, equivalent on perimeter: a = 24.7 mm, b = 6.25 mm.

[5]. Diameter, equivalent on perimeter: a = 11.25 mm, b = 4.8 mm.
ENDFOOTNOTE.

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Due to the deviations of the calculated values of the diameter of wire and thickness of insulation from the nominal, the calculation of windings cannot be very precise. Normally the disagreement between the actual and calculated resistor/resistance can reach to ±10o/o. With small diameters of wire (0.05-0.09) mm this disagreement increases to ±15o/o. For calculating supplementary resistor/resistances Table 6.3 gives resistor/resistance 1 m of wire by diameter from 0.03 to 1.0 mm from alloy with high specific resistor/resistance.

## 6.6. Overall dimensions of the coils of relay.

For the calculation of the windings of relay, it is

necessary to know the overall dimensions of coils and the value of the winding space of standard relays. Table 6.4 gives the size/dimensions of winding space for all fundamental types of relay.

In this table for relay of the type RPN (in second column) corrected values of the equivalent on perimeter inner diameter of winding $D'_0$.

The windings of the deferred-action for function relays of the type RKN have length of 0.8 mm less than the winding of the relay of those who were retarded for release/tempering.

The useful height/altitude of winding/coil h must be less than the interior height of the jaw of coil H on 0.5-0.8 mm in order to ensure the possibility of the attachment of conclusion/derivations and external pasting (seal) of coil. Filling of the useful winding space of coil with wire by diameter to 0.10 mm must not exceed 90o/o, but with high diameters 96o/o.

6-7. Insulation of windings.

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The windings of relay usually are coiled on framework/bodies from heat-resistant plastic.

For an airtight relay it is necessary to apply the special plastic, which does not isolate during heating of the organic and water vapors, which upset the operation of contacts. Frame-less windings are insulated from core by film from teflon, by glass cloth, triacetate film, varnished insulating cloth or the lacquered paper by thickness from 0.02 to 0.1-0.15 mm.

Between windings with low voltages, runs itself telephone or cable paper. The windings of the relay of alternating current, workers with stresses 220-380 V, are

divided usually into 2-4 parts with separators of condenser/capacitor paper for the exception/elimination of the breakdowns between their individual parts. From above winding they are usually shielded by the cable paper and silk varnished insulating cloth, or the lacquered paper.

For the selection of thickness and determining a quantity of layers of insulation depending on the value of operating stress table 6-5 gives the effective values of the breakdown and worker of the stresses of different insulation.

In this table are given the breakdown voltages of materials in as-received condition. After the ageing of varnished insulating clothes for 18 h at temperature, 100°C breakdown voltage on bend decreases approximately 1.5-2 times, while after extension along diagonal with effort/force 0.4 kgf/cm², it decreases 4-5 times. The operating stress of insulation usually is accepted 10 times of less initial breakdown voltage.

The windings of the relays, working under conditions of the increased humidity and vibration, it is desirable to saturate with insulating varnishes or compounds. Saturation

is usually conducted in vacuum by heat-resistant varnish No 447. The operating stress of the saturated paper can be increased two times.

According to the existing norms for electrical apparatuses and installations with operating stress to 60 V into testing voltage, it is equal to 500 V effective, with operating stresses from 60 to 250 V - 1500 V and from 250 to 500 V - 2000 V eff. However, in the miniature/small and miniature relays, working in radio-electronic equipment, these norms cannot be maintained, since the distances between the current-carrying parts of these relays are very small. The values of testing voltages for a miniature/small and miniature relay are given below, into § 18-4.

Value of the breakdown voltage of insulation depends on the duration of the action of testing voltage. Usually by norms is provided the duration of breakdown test 1 min; if testing is conducted not more than 1 s, then the value of testing voltage must be increased by 25o/o.

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Table 6-5. Insulation for the windings of relay.

| (1) Материалы | (2) Марка | (3) Толщина, мм | (4) Пробивное напряжение (8) $E_d$, кв/мм | (9) $E$, кв | (5) Рабочее напряжение $U$, в | (6) Удельное объемное сопротивление $\rho$, ом·см | (7) Нагревостойкость, °С |
|---|---|---|---|---|---|---|---|
| (10) Конденсаторная бумага | КОН-1 | 0,005 | 50 | 0,25 | 25 | — | 90 |
| » » | КОН-1 | 0,010 | 30 | 0,30 | 30 | — | 90 |
| » » | КОН-1 | 0,015 | 23 | 0,35 | 35 | — | 90 |
| » » | КОН-1 | 0,030 | 16 | 0,48 | 48 | — | 90 |
| » » | КОН-2 | 0,010 | 35 | 0,35 | 35 | — | 90 |
| » » | КОН-2 | 0,030 | 19 | 0,56 | 56 | — | 90 |
| (11) Телефонная бумага | КТН | 0,05 | 10 | 0,50 | 50 | — | 90 |
| (12) Кабельная бумага | К-08 | 0,08 | 7—8 | 0,60 | 60 | — | 90 |
| » » | К-12 | 0,12 | 8—8,5 | 1,00 | 100 | — | 90 |
| » » | К-17 | 0,17 | 7—8 | 1,20 | 120 | — | 90 |
| (13) Лакированная бумага | — | 0,06 | 30 | 1,8 | 180 | — | 105 |
| » » | — | 0,10 | 30 | 3,0 | 300 | — | 105 |
| (14) Лакоткань хлопчатобумажная | ЛХ1 | 0,15 | 14—28 | 2,1 | 210 | $10^{11}$—$10^{12}$ | 105 |
| (15) Лакоткань шелковая | ЛШС | 0,05 | 20—45 | 1,0 | 100 | $10^{12}$—$10^{13}$ | 105 |
| » » | ЛШС | 0,12 | 35—40 | 4,2 | 420 | $10^{12}$ | 105 |
| » » | ЛШ1 | 0,10 | 30—50 | 3,0 | 300 | $10^{12}$ | 105 |
| » » | ЛШ2 | 0,08 | 20—34 | 1,6 | 160 | $10^{12}$ | 105 |
| » » | ЛШ2 | 0,10 | 20—36 | 2,0 | 200 | $10^{12}$ | 105 |
| (16) Стеклоткань | ЭСТБ | 0,04 | 10—14 | 0,4 | 40 | | |
| (17) Стеклолента бесщелочная | — | 0,1 | 7—10 | 0,7 | 70 | $10^{11}$—$10^{13}$ | 250—300 |
| (18) Стеклолента бесщелочная | — | 0,15 | 6—9 | 0,9 | 90 | $10^{11}$—$10^{13}$ | 250—300 |
| (19) Стеклолакоткань | ЛСК-7 | 0,06 | 20—25 | 1,2 | 120 | $10^{12}$—$10^{14}$ | 180 |
| » | ЛСК-7 | 0,11 | 20—28 | 2,2 | 220 | $10^{12}$—$10^{14}$ | 180 |
| » | ЛСК-7 | 0,15 | 20—28 | 3,0 | 300 | $10^{12}$—$10^{14}$ | 180 |
| (20) Фторопласт-3 | — | 0,05 | 60—150 | 3,0 | 300 | $10^{13}$—$10^{17}$ | 150 |
| (21) Янтарь | — | — | 13—15 | — | — | $10^{17}$—$10^{19}$ | 175—200 |
| (22) Пленка из фторопласта-4 ориентированная | — | 0,04 | 40—100 | 4,0 | 200 | $10^{16}$—$10^{17}$ | 260—280 |
| (23) Триацетатная пленка | — | 0,05 | 80—100 | 4,0 | 400 | $10^{13}$—$10^{15}$ | 100 |
| (24) Полистирол | — | 0,05 | 20—50 | 2,5 | 250 | $10^{17}$—$10^{18}$ | 70—80 |
| (25) Полиэтилен | — | 0,05 | 45—60 | 2,2 | 220 | $10^{16}$—$10^{17}$ | 80—100 |
| (26) Полиамиды (капрон, нейлон) | — | 0,05 | 30—60 | 1,5 | 150 | $10^{12}$ | 80—100 |
| (27) Полихлорвинил | — | 0,05 | 50—75 | 2,5 | 250 | $10^{12}$—$10^{14}$ | 60—65 |

Continuation table 6-5.

| (1) Материалы | (2) Марка | (3) Толщина, мм | (4) Пробивное напряжение | | (5) Рабочее напряжение U, в | (6) Удельное объемное сопротивление ρ, ом·см | (7) Нагревостойкость, °C |
|---|---|---|---|---|---|---|---|
| | | | (8) $E_d$, кв/мм | (9) E, кв | | | |
| (28) Проволока диаметром 0,03—0,04 мм | ПЭЛ | — | — | 0,3 | 30 | — | — |
| (28) Проволока диаметром 0,05—0,07 мм | ПЭЛ | — | — | 0,35 | 35 | — | — |
| (28) Проволока диаметром 0,10—0,13 мм | ПЭЛ | — | — | 0,4 | 40 | — | — |
| (28) Проволока диаметром 0,10—0,13 мм | ПЭВ1 | — | — | 0,5 | 50 | — | — |
| (28) Проволока диаметром 0,10—0,13 мм | ПЭВ2 | — | — | 0,7 | 70 | — | — |
| (28) Проволока диаметром 0,15—0,20 мм | ПЭЛ | — | — | 0,55 | 55 | — | — |
| (28) Проволока диаметром 0,15—0,20 мм | ПЭВ1 | — | — | 0,6 | 60 | — | — |
| (28) Проволока диаметром 0,15—0,20 мм | ПЭВ2 | — | — | 0,8 | 80 | — | — |

Key: (1). Materials. (2). Brand. (3). Thickness, mm. (4). Breakdown voltage. (5). Operating stress U, V. (6). Volume resistivity ρ, Ω•cm. (7). heat resistance, °C. (8). kg/mm. (9). kg. (10). Condenser/capacitor paper. (11). Telephone paper. (12). The cable paper. (13). The lacquered paper. (14). Varnished vinsulating cloth is cotton. (15). Varnished insulating cloth is silk. (16). Glass cloth. (17). Fiberglass tape is alkali-free. (18). Fiberglass tape is alkali-free. (19). Impregnated glass cloth. (20). Polychlorotrifluoroethylene. (21). Amber. (22). Film from teflon oriented. (23). Triacetate film. (24). Polystyrene.

(25). Polyethylene. (26). Polyamides (caprone, nylon). (27). Polyvinyl chloride. (28). Wire by diameter.

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Table 6-6 gives the results of the tests of the breakdown voltage of insulation of windings and contact springs of some types of relay under normal conditions.

To Fig. 6-2, are given the integral distribution curves of the breakdown voltage between winding and housing of the relay of types RES6, RES9 and of RMUG, constructed according to L. E. Bel'skoy's data. From these curves it follows that the average value of the breakdown voltage of relay of the type RES9 is equal to 2020 V eff., but 1o/o of relay there can be probit with voltage 1160 V eff.

Table 6-6. Tentative values of breakdown voltages. (With p = 760 mm Hg; $\theta_0$ = +20°C; f = 50 Hz).

| (1) Тип реле | (2) Между обмоткой и корпусом $U_{пр}$, в эфф. | (3) Между контактными пружинами и корпусом $U_{пр}$, в эфф. | (4) Между контактами $U_{пр}$, в эфф. |
|---|---|---|---|
| РКН | 1100—2200 | 1200—1500 | — |
| РКМП | 1200—2200 | 1200—2000 | — |
| РПН | 900—1700 | 700—2000 | — |
| РС-13 | 800—1200 | 1000—1800 | — |
| РС-52 | 1600—2200 | 1400—2800 | 1500—2500 |
| РМУ | 1600—2500 | 1300—2500 | 1200—2200 |
| РМУГ | 1700—3000 | 1400—2500 | 1400—2500 |
| РЭС6 | 1200—1900 | 1200—1800 | 1000—2300 |
| РЭС9 | 1300—2600 | 1800—3200 | 1200—1800 |
| РЭС10 | 1700—2600 | 1200—1800 | 1100—1700 |

Key: (1). Type of relay. (2). Between winding and housing ___ V eff. (3). Between contact springs and housing ___ V eff. (4). Between contacts ___ V eff.

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With an increase in the frequency, breakdown strength of air decreases. To Fig. 6-3, is given the curve of dependence on the frequency of the relation of breakdown strength of air at high frequency to breakdown voltage at zero frequency. This nodring it has a minimum at frequencies $10^6$-$10^7$ Hz.

The insulation resistance of winding and contacts under normal conditions (at relative humidity 65 ± 15o/o and temperature +20 ±5°C) must be not less than 100-500 MΩ (virtually it reaches to $10^5$-$10^6$ MΩ). With the increased humidity the insulation resistance decreases and must be not less than 1-10 MΩ.

6-8. Tables for the calculation of the windings of relay.

The analytical method of the calculation of the windings of relay, presented above, it gives sufficiently accurate results, but it requires sufficiently much time for computations.

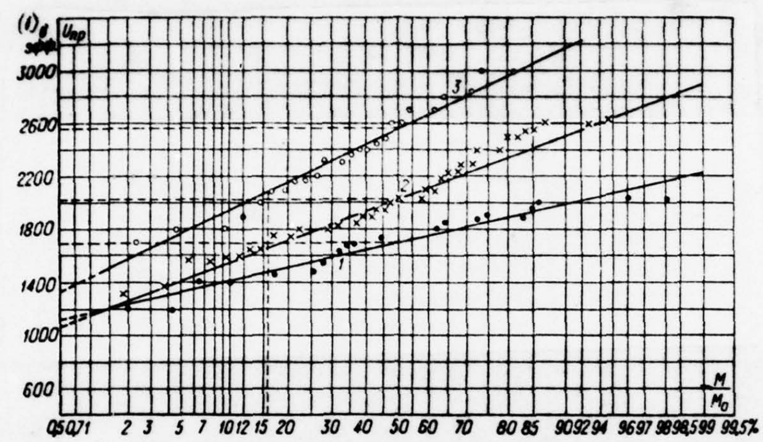


**Fig. 6-2. The integral distribution curves of the breakdown voltage between winding and housing of relay. 1 - type RES6 ($M_o$ = 47); 2 - type RES9 ($M_o$ = 54); 3 - type RMUG ($M_o$ = 42).**

Key: (1). V eff.

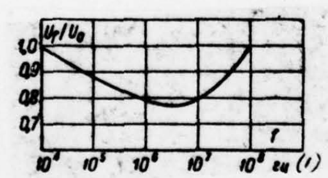


Fig. 6-3. Curved of dependences on the frequency of the relation of breakdown strength of air at high frequency to breakdown voltage at zero frequency.

Key: (1). Hz.

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Table 6-7. Resistor/resistance and the turn number of the winding of relay of the type RPN with 100o/o filling of the winding space of coil.

(a) Проволока красномедная марки ПЭЛ ($\Theta_0 = +20°$ C)

| Диаметр проволоки $d$, мм (1) | Сопротивление $R$, ом (2) | Число витков $w$ (3) | Число витков в двух рядах (4) | Коэффициент полноты обмотки $k_f$ (5) | Диаметр проволоки $d$, мм (1) | Сопротивление $R$, ом (2) | (3) Число витков $w$ | (4) Число витков в двух рядах | Коэффициент полноты обмотки $k_f$ (5) |
|---|---|---|---|---|---|---|---|---|---|
| 0,05 | 34 800 | 78 000 | — | 1.23 | 0.38 | 14,3 | 1870 | 224 | 1.04 |
| 0,06 | 17 900 | 58 600 | — | 1.23 | 0.41 | 10,8 | 1630 | 208 | 1,04 |
| 0,07 | 10 300 | 45 600 | — | 1,23 | 0,44 | 8,04 | 1400 | 194 | 1,04 |
| 0,08 | 6 340 | 35 500 | — | 1,22 | 0,47 | 6,23 | 1240 | 182 | 1,04 |
| 0,09 | 4 030 | 29 000 | — | 1,21 | 0,49 | 5,26 | 1130 | 176 | 1,04 |
| 0,10 | 2 550 | 22 900 | — | 1,19 | 0,51 | 4,50 | 1050 | 168 | 1,04 |
| 0,11 | 1 810 | 19 600 | — | 1,17 | 0,53 | 3,90 | 980 | 162 | 1,03 |
| 0,12 | 1 290 | 16 800 | — | 1,15 | 0,55 | 3,36 | 917 | 156 | 1,03 |
| 0,13 | 970 | 14 600 | — | 1,14 | 0,57 | 2,95 | 858 | 152 | 1,03 |
| 0,14 | 733 | 12 900 | — | 1,13 | 0,59 | 2,55 | 805 | 146 | 1,03 |
| 0,15 | 565 | 11 400 | — | 1,12 | 0,62 | 2,13 | 735 | 140 | 1,03 |
| 0,16 | 440 | 10 100 | — | 1,11 | 0,64 | 1,88 | 693 | 136 | 1,03 |
| 0,17 | 353 | 9 140 | — | 1,10 | 0,67 | 1,58 | 636 | 130 | 1,03 |
| 0,18 | 282 | 8 200 | 470 | 1,10 | 0,69 | 1,40 | 600 | 127 | 1,03 |
| 0,19 | 229 | 7 400 | 444 | 1,10 | 0,72 | 1,17 | 542 | 120 | 1,03 |
| 0,20 | 180 | 6 500 | 418 | 1,06 | 0,74 | 1,04 | 575 | 117 | 1,03 |
| 0,21 | 151 | 5 970 | 400 | 1,06 | 0,77 | 0,898 | 478 | 113 | 1,03 |
| 0,23 | 107 | 5 070 | 368 | 1,06 | 0,80 | 0,777 | 446 | 109 | 1,03 |
| 0,25 | 78 | 4 340 | 342 | 1,06 | 0,83 | 0,670 | 416 | 105 | 1,03 |
| 0,27 | 54 | 3 540 | 308 | 1,05 | 0,86 | 0,585 | 390 | 102 | 1,03 |
| 0,29 | 41,2 | 3 120 | 290 | 1,05 | 0,90 | 0,495 | 358 | 97 | 1,03 |
| 0,31 | 30,9 | 2 690 | 268 | 1,05 | 0,93 | 0,432 | 335 | 95 | 1,03 |
| 0,33 | 24,8 | 2 410 | 254 | 1,05 | 0,96 | 0,377 | 311 | 92 | 1,03 |
| 0,35 | 19,5 | 2 160 | 242 | 1,05 | 1,00 | 0,324 | 288 | 88 | 1,03 |

(b) Проволока константановая марки ПЭШОК ($\rho = 0,48$ ом · мм²/м)
Коэффициент полной обмотки $k_f = 1$

| $d$, мм | (6) $R$, ом | $w$ | (7) Число витков в двух рядах | $d$, мм | (6) $R$, ом | $w$ | (7) Число витков в двух рядах |
|---|---|---|---|---|---|---|---|
| 0,06 | 126 700 | 15 000 | — | 0,20 | 2440 | 3220 | 300 |
| 0,07 | 82 600 | 13 200 | — | 0,25 | 1075 | 2220 | 248 |
| 0,08 | 56 100 | 11 600 | — | 0,30 | 586 | 1740 | 220 |
| 0,09 | 40 200 | 10 300 | — | 0,35 | 331 | 1340 | 192 |
| 0,10 | 24 000 | 7 940 | — | 0,40 | 211 | 1105 | 176 |
| 0,12 | 13 900 | 6 580 | — | 0,45 | 135 | 896 | 156 |
| 0,15 | 6 860 | 5 100 | 376 | 0,50 | 94,7 | 765 | 146 |
| 0,18 | 3 690 | 3 940 | 330 | | | | |

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)
MAR 78 M I VITENBERG
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Key: (a). Wire red copper of the brand of PEL (___ = +20°C). (1). diameter of wire, d, mm. (2). Resistor/resistance R, mm. (3). Turn number, w. (4). Turn number in two series. (5). Solidity ratio of winding (b). Wire constantan of the brand PEShOK ($\rho$ = 0.48 $\Omega \cdot mm^2/m$). Coefficient of complete winding ____. (6). ohm. (7). Turn number in two series.

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Table 6-8. Auxiliary table for the calculation of resistor/resistance and turn number of the winding of relay of the type RPN with partial filling of the winding space of coil.

| R % — | | — w % | R % — | | — w % | R % — | | — w % |
|---|---|---|---|---|---|---|---|---|
| w % — | — R % | | w % — | — R % | | w % — | — R % | |
| 1 | 0,59 | 1,7 | 40 | 30,1 | 50,3 | 79 | 72,2 | 84,4 |
| 2 | 1,19 | 3,3 | 41 | 31,0 | 51,3 | 80 | 73,4 | 85,2 |
| 3 | 1,80 | 4,9 | 42 | 31,9 | 52,3 | 81 | 74,7 | 85,9 |
| 4 | 2,42 | 6,5 | 43 | 32,8 | 53,3 | 82 | 75,9 | 86,7 |
| 5 | 3,04 | 8,1 | 44 | 33,8 | 54,3 | 83 | 77,2 | 87,5 |
| 6 | 3,68 | 9,6 | 45 | 34,7 | 55,8 | 84 | 78,5 | 88,3 |
| 7 | 4,32 | 11,1 | 46 | 35,7 | 56,2 | 85 | 79,8 | 89,1 |
| 8 | 4,97 | 12,5 | 47 | 36,7 | 57,2 | 86 | 81,1 | 89,8 |
| 9 | 5,63 | 13,9 | 48 | 37,7 | 58,1 | 87 | 82,3 | 90,56 |
| 10 | 6,30 | 15,3 | 49 | 38,7 | 59,0 | 88 | 83,6 | 91,28 |
| 11 | 6,96 | 16,7 | 50 | 39,7 | 59,9 | 89 | 84,9 | 92,02 |
| 12 | 7,65 | 18,1 | 51 | 40,7 | 60,8 | 90 | 86,2 | 92,76 |
| 13 | 8,34 | 19,4 | 52 | 41,7 | 61,7 | 91 | 87,6 | 93,50 |
| 14 | 9,05 | 20,7 | 53 | 42,7 | 62,6 | 92 | 89,0 | 94,24 |
| 15 | 9,74 | 22,1 | 54 | 43,7 | 63,5 | 93 | 90,3 | 94,97 |
| 16 | 10,5 | 23,4 | 55 | 44,7 | 64,5 | 94 | 91,7 | 95,70 |
| 17 | 11,2 | 24,7 | 56 | 45,8 | 65,4 | 95 | 93,0 | 96,43 |
| 18 | 11,9 | 25,9 | 57 | 46,8 | 66,3 | 96 | 94,4 | 97,16 |
| 19 | 12,7 | 27,1 | 58 | 47,9 | 67,2 | 97 | 95,8 | 97,87 |
| 20 | 13,4 | 28,4 | 59 | 49,0 | 68,0 | 98 | 97,2 | 98,58 |
| 21 | 14,2 | 29,6 | 60 | 50,1 | 68,8 | 99 | 98,6 | 99,29 |
| 22 | 14,9 | 30,8 | 61 | 51,2 | 69,7 | 100 | 100,0 | 100,0 |
| 23 | 15,7 | 31,9 | 62 | 52,3 | 70,6 | | | |
| 24 | 16,5 | 33,1 | 63 | 53,4 | 71,4 | | | |
| 25 | 17,2 | 34,3 | 64 | 54,5 | 72,3 | | | |
| 26 | 18,0 | 35,4 | 65 | 55,6 | 73,2 | | | |
| 27 | 18,8 | 36,5 | 66 | 56,7 | 74,0 | | | |
| 28 | 19,7 | 37,7 | 67 | 57,8 | 74,8 | | | |
| 29 | 20,5 | 38,8 | 68 | 59,0 | 75,7 | | | |
| 30 | 21,3 | 39,9 | 69 | 60,2 | 76,5 | | | |
| 31 | 22,2 | 41,0 | 70 | 61,3 | 77,3 | | | |
| 32 | 23,0 | 42,0 | 71 | 62,5 | 78,1 | | | |
| 33 | 23,8 | 43,1 | 72 | 63,7 | 78,9 | | | |
| 34 | 24,7 | 44,2 | 73 | 64,8 | 79,7 | | | |
| 35 | 25,6 | 45,2 | 74 | 66,0 | 80,5 | | | |
| 36 | 26,5 | 46,2 | 75 | 67,2 | 81,3 | | | |
| 37 | 27,4 | 47,3 | 76 | 68,5 | 82,1 | | | |
| 38 | 28,3 | 48,3 | 77 | 69,7 | 82,9 | | | |
| 39 | 29,2 | 49,3 | 78 | 70,9 | 83,6 | | | |

(1) Потери, вносимые короткозамкнутой обмоткой

| (2) Высота короткозамкнутой обмотки | $R_{кз}$, % | $w_{кз}$, % |
|---|---|---|
| 1 мм | 9,9 | 15,2 |
| 2 мм | 21,7 | 30,4 |
| 3 мм | 35,3 | 46,6 |

Key: (1). Losses, introduced by quadrature winding. (2). Height/altitude of quadrature winding.

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Therefore for the calculation of the windings of standard relays, frequently are applied tables or curve/graphs (diagrams), which make it possible to considerably simplify and to accelerate the calculation of windings.

For the calculation of the windings of relay of the type RPN, they are applied by table 6-7 and 6-8. Table 6-7 gives turn number and winding impedance of relay of the type RPN with complete (100o/o) filling of the winding space of coil for the nominal diameters of red copper wire from 0.05 to 1.0 mm of the brand of PEL.

During the determination of a quantity of turns of the wire of each diameter in this table, was considered the maximum possible wire diameter with insulation.

To the account for the inequality of the laying of

wire with winding/coil (quality of winding/coil) in the last/latter graph of table are given the values of the solidity ratios of winding $k_f$, which are reciprocal value of the coefficients of the inequality of laying $k_н$.

Filling of the winding space of coil is composed of filling in percentages according to turn number with consideration the solidity ratio of winding, loss of winding space from the paper separators between series and windings - $\%w_б$ and the loss of winding space as a result of the presence of short circuit of winding $\%w_{кз}$.

$$h\% = \Sigma\%w \cdot k_f + \Sigma\%w_б + \%w_{кз}. \qquad (6\text{-}27)$$

To the seal (liner) of each winding of relay, is lost $\%w_б = 2{,}5\%$ winding space. Filling of coils it is desirable to select not more than 96o/o.

For the calculation of the windings of resistor/resistances and combined windings table 6-7 gives also the turn number and winding impedances from constantan wire by diameter from 0.06 to 0.5 mm of the brand PEShOK.

Second auxiliary table 6-8 makes it possible to perform the calculation of the windings of relay of the type RPN

with partial (less than 100o/o) filling of the winding space of coil. This table has three graphs: in the first graph are given the percentages of filling of coil according to turn number from 0 to 100o/o, in the second graph are given the corresponding values of winding impedance in percentages from the nominal value of winding impedance and in the third - the percentages of filling of coil, according to turn number corresponding to the whole values of the percentages of winding impedance from 0 to 100o/o; given in the first graph.

6-9. Diagrams for the calculation of the windings of relay.

For facilitation and accelerating the selection of the windings of relay, can be also used the diagrams. These diagrams are the curved dependences of winding impedance on turn number with the different wire diameters.

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Along the axes of ordinates and abscissas of diagram, are deposit/postponed on logarithmic scale the resistor/resistance

and the turn number of winding. At an angle of approximately 45° to the axis of abscissas, are given the lines of the height/altitude of the winding/coils which intersect by the curves of the equal wire diameters. To Figs. 6-4 and 6-5, are given the diagrams for the calculation of the windings of the relay of types RPN and RKN.

For the calculation of winding according to the assigned resistor/resistance (or turn number) it is necessary to find a to diagram the intersection of the line, which corresponds to the assigned resistor/resistance (or turn number) with curves the equal wire diameter.

A quantity of curves of equal diameter, by the secant of the assigned resistor/resistance or turn number, gives the number of solutions of problem within these altitude limits of winding/coil.

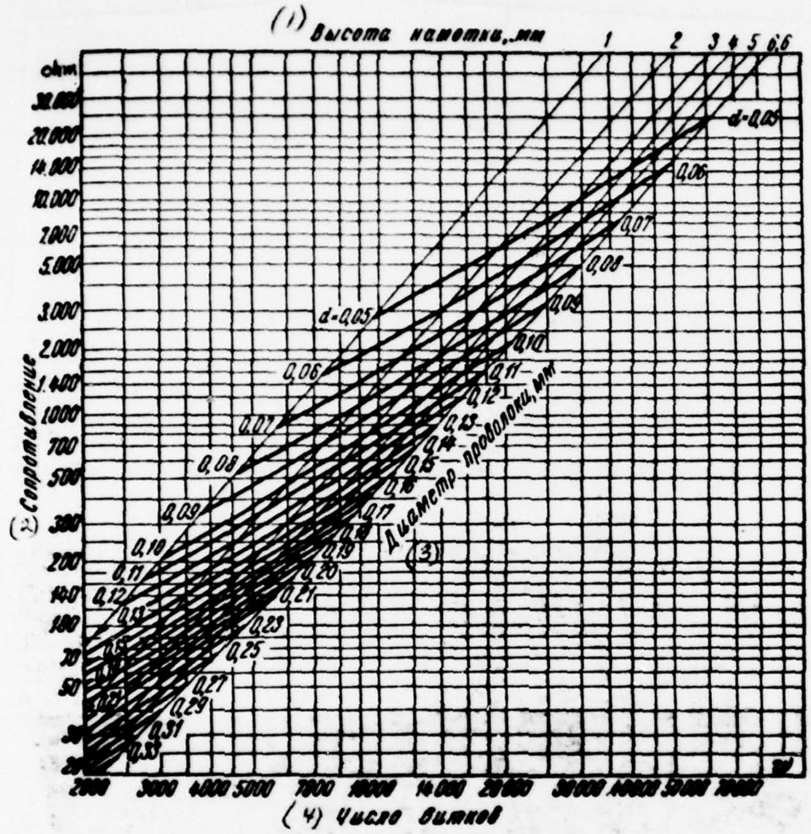


Fig. 6-4. Diagram for the calculation of the windings of relay of the type RFN (wire of the brand PEL $\theta_0$ = +20°C).

Key: (1). Height/altitude of winding/coil, mm. (2). Resistor/resistance. (3). Diameter of wire, mm. (4). Turn number.

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The minimum consumption of copper for winding will be in the case of the selection of the solution of problem, which corresponds to the minimum height/altitude of winding/coil. For the calculation of winding according to those who were assigned to turn number and to resistor/resistance it is necessary to find the point of intersection of the lines, which correspond to the assigned magnitudes. If this point will lie/rest on any of the curves the equal wire diameter, then is possible the exact solution of problem. Otherwise the exact solution of this problem can be reached by change in the inner diameter of the winding or by the connection/inclusion of supplementary resistor/resistance, since the nominal wire diameters differ from each other no less than by 0.01 mm. Approximate solution can be obtained, if we step back from the assigned conditions, after changing the assigned magnitude of resistor/resistance or turn number so that the point of intersection of the lines of resistor/resistance and turn number would lie to the nearest curve of the wire diameter.

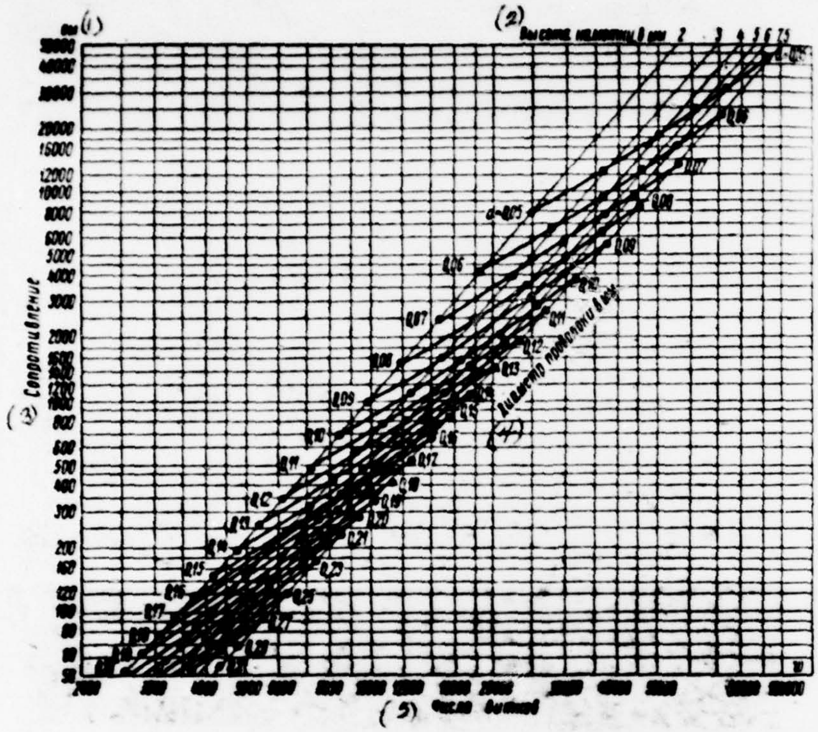

Fig. 6-5. Diagram for the calculation of the windings of relay of the type RKN (wire of the brand of PEL, $\theta_0$ = +20°C).

Key: (1). ohm. (2). Height/altitude of winding/coil in mm. (3). Resistor/resistance. (4). Wire diameter in mm. (5). Turn number.

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During the calculation of winding according to the assigned wire diameter, the number of solutions can be very greatly, and they all will lie/rest on curve for this wire diameter.

With the aid of these diagrams it is possible to design also double wound coils.

The first winding of two-winding coil is designed from diagram normally, but in this case is selected the smallest possible height/altitude of winding/coil, in order for the remaining windings of coil to leave sufficient winding space.

For determining the turn number and resistor/resistance of the second winding, it is necessary tc find from diagram the appropriate values of the parameters which would possess the coil, if it had one winding. Then from the obtained values it is necessary to deduct respectively turn number and the resistor/resistance which would have the first winding of coil, if it was wound from the wire of the same diameter, as the second winding.

Of time-lag relay of the type RKN, the length of coil is less; therefore for the calculation of the windings of time-lags relay it is necessary of the value of the turn number and winding impedance, obtained from diagrams, to multiply by the appropriate values of coefficient of n. The assigned values of the turn number and winding impedance must be, on the contrary, divided into the value of this coefficient. For relay with plug length 12.5, 25.5 and 38 mm of the value of coefficients n, are respectively equal to 0.755, 0.562 and 0.344.

6-10. Examples.

1. Relays of type RPN with quadrature winding of two layers of wire as diameter 0.5 mm (h = 1 mm) must have two windings.

Table 6-9. On the calculation of the windings of relay of **the type RPN.**

| Обмотка (1) | Диаметр провода d, мм (2) | Сопротивление (3) R, ом (8) | Сопротивление (3) R, % | Заполнение по виткам w, % (4) | Число витков (5) Вычисленное w (9) | Число витков (5) Округленное w (10) | Заполнение катушки h, % (6) | Примечание (7) |
|---|---|---|---|---|---|---|---|---|
| | — | — | 9,9 | 15,2 | — | — | 15,2 | (11) Короткозамкнутая обмотка |
| I | 0,16 | 160 | 36,4 | 41,3 → | 4172 | 4200 | 45,8 | — |
| — | — | — | 46,3 → | 56,5 | — | — | — | (12) Сумма |
| — | — | — | — | 2,5 | — | — | 2,5 | Прокладка (13) |
| — | — | — | 49,0 | 59,0 | — | — | — | — |
| II | 0,10 | 700 | 27,45 | 23,46 | 5372 | 5350 | 27,9 | — |
| — | — | — | 76,45 → | 82,46 | — | — | 91,4 | (12) Сумма |

Key: (1). Winding. (2). Diameter of wire d, mm. (3). Resistor/resistance. (4). Filling on turns w, o/o. (5). Turn number. (6). Filling of coil h, o/o. (7). Note. (8). ohm. (9). Calculated w. (10). Rounded w. (11). Quadrature winding. (12). Sum. (13). Separator.

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Resistor/resistance of the first winding 160 ohm, wire red copper with enamel insulation of brand PEL, diameter 0.16 mm. Second winding 700 chm, wire the same, diameter 0.10 mm. It is necessary to determine the turn number of both

windings.

Calculation is carried out in the form table 6-9. In the first row of this table, are written the losses in the percentages of resistor/resistance and turn numbers, caused by quadrature winding. The sum of the resistor/resistance of the short-circuited and first winding is 46.3o/o.

Table 6-10. On the calculation of the windings of relay of the type RPN.

| (1) Обмотка | (2) Диаметр провода d, мм | (3) Число витков w | (4) Заполнение по виткам w, % | (5) Заполнение катушки h, % | (6) Сопротивление R, % | (7) Вычисленное R, ом | (8) Округленное R, ом | (9) Примечание |
|---|---|---|---|---|---|---|---|---|
| — | — | — | 15,2 | 15,2 | 9,9 | — | — | (10) Короткозамкнутая обмотка |
| I | 0,16 | 4200 | 41,6 | 46,2 | 36,7 | 161,5 | 160 | — |
| — | — | — | 56,8 → | | 46,6 | — | — | (11) Сумма |
| — | — | — | 2,5 | 2,5 | — | — | — | (12) Прокладка |
| — | — | — | 59,3 → | | 49,3 | — | — | — |
| II | 0,10 | 5850 | 23,35 | 27,8 | 27,45 | 700 | 700 | — |
| — | — | — | 82,65 → | | 76,75 | — | — | (11) Сумма |
| — | — | — | — | 91,7 | — | — | — | — |

(1). Winding. (2). Diameter of wire d, mm. (3). Turn number w. (4). Filling on turns w, o/o. (5). Filling of coil h, o/o. (6). Resistor/resistance. (7). Calculated R, ohm. (8). Rounded R, ohm. (9). Note. (10). Quadrature winding. (11). Sum. (12). Separator.

Table 6-11. On the calculation of the symmetrical winding of relay of the type RPN.

| (1) Обмотки | (2) Диаметр провода d, мм | (3) Число витков w | (4) Заполнение по виткам w, % | (5) Заполнение катушки h, % | (6) Сопротивление R, % | (7) Вычисленное R, ом | (8) Округленное R, ом | (9) Примечание |
|---|---|---|---|---|---|---|---|---|
| Ia | 0,14 | 2600 | 20,2 | 22,8 | 13,6 | 99,7 | 99,0 | — |
| | | | 2,5 | 2,5 | — | — | — | (10) Прокладка |
| | | | 22,7 | | 15,5 | — | — | (11) Сумма |
| II | 0,14 | 5200 | 40,4 | 45,6 | 38,0 | 278,5 | 275 | — |
| | — | — | 63,1 | | 53,5 | — | — | (11) Сумма |
| | — | — | 2,5 | 2,5 | — | — | — | (10) Прокладка |
| | — | — | 65,6 | | 56,3 | — | — | (11) Сумма |
| Iб | 0,14 | 2600 | 20,2 | 22,8 | 24,5 | 179 | 176 | — |
| | — | — | 85,8 | | 80,8 | — | — | (11) Сумма |
| | | | | 96,2 | | | | |

Key: (1). Windings. (2). Diameter of wire d, mm. (3). Turn number w. (4). Filling on turns w, o/o. (5). Filling of coil h, o/o. (6). Resistor/resistance. (7). Calculated R, ohm. (8). Rounded R, ohm. (9). Note. (10). Separator. (11). Sum.

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From table 6-7 we find the appropriate percentage of the turns: 56.5o/o. The winding space, necessary for the first winding, will be equal to 56.5-15.2 = 41.3o/o, the turn number of this winding 10100•0.413 = of 4172 turns, also,

after rounding 4200. The second winding is insulated from by the first paper separator, which occupies winding space on turns, equal to 2.5o/o.

In a similar manner we find the winding space, necessary for the second winding. The turn number of the latter is equal to 5372 or, after rounding, 5350. The common/general/total filling of the coil of double-coiled relay is equal to 91.4o/o.

2. Relays of type RPN with quadrature winding (h = 1 mm).

The first winding of relay has 4200 turns of the wire PEL as a diameter 0.10 mm. It is necessary to determine the resistor/resistance of both windings.

The solution of this problem is given in table 6-10.

3. Relays of type RPN must have two windings with identical turn number $w_1 = w_2 = 5200$, that have one and the same resistor/resistance $r_1 = r_2$ (symmetrical winding). Wire red copper the brand PEL with diameter 0.14 mm.

The first winding it is divisible to two identical parts on 2600 turns and the second halves of this winding we coil after the second winding.

Calculation of this winding is given in table 6-11.

4. Table 6-12 gives calculation of series winding of relay of type RPN.

Table 6.12. On the calculation of series winding of type RPH.

| (1) Обмотка | d, мм | w | (2) Заполнение по виткам w, % | Заполнение катушки h, % (3) | R, % | Вычисленное R, ом (4) | Округленное R, ом (5) | (6) Примечание |
|---|---|---|---|---|---|---|---|---|
| I | 0,72 | 420 | 77,5 | — | 70,3 | 0,8225 | 0,82 | (7) — |
| | — | 480 | 88,6 | 91,3 | — | — | — | При 4-х двойных рядах |
| | | | 2,5 | 2,5 | | | | (8) Прокладка |
| | | | 91,1 | 93,8 | | | | (9) Сумма |

Chapter Seven.

Calculation of relays, connected in different circuits.

7-1. Fundamental methods of the calculation of the windings of relay in circuits.

The calculation of the winding of the relay, connected in any circuit, consists in the determination of the turn number and resistor/resistance of this winding, necessary for providing the required or maximally possible ampere-turns in this circuit.

Depending on circuit conditions, the relay can be included:

1) into simple circuit in series with resistor/resistance;

2) into the compound circuit in which are included different resistor/resistances, consecutively and in parallel to winding or;

3) into local circuit it is direct to battery.

To calculate windings in these circuits is possible by two methods:

1) for filling of entire winding space of coil or;

2) for minimum filling of the winding space of coil (minimum consumption of copper).

The first method in turn, is divided into three cases: a) calculation a assigned ampere-turns, b) calculation for maximum ampere-turns and c) calculation for maximum external resistor/resistance.

The calculation of the winding of relay for the assigned ampere-turns usually has two solutions: the first gives winding with maximally possible turn number and the greatest resistor/resistance (with the assigned ampere turns and these size/dimensions of coil), the second - winding with smallest possible turn number and minimum resistor/resistance (under the same conditions).

Therefore the calculation of the winding of relay for filling of entire winding space of coil is utilized only when it is necessary to ensure the minimum energy consumption of battery and to obtain winding with large inductance or, on the contrary, when it is necessary to relay with low resistor/resistance and small inductance (for example, group relay, test relay and the like).

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In other cases the calculation of relay is conducted for minimum filling of the winding space of coil, since in this case is provided the smallest consumption of copper for winding with the assigned ampere-turns. For minimum filling of the winding space of coil, are designed also the first windings of multiwinding coils, since in this case for the arrangement/position of the remaining windings of coil remains larger winding space.

7-2. Calculation of the relay, connected in series with resistor/resistance, for filling of entire winding space of

coil.

a) the calculation for the assigned ampere-turns.

With the minimum value of the operating voltage of battery $U_1$, possible in operation, relay series-connected with resistor/resistance R (Fig. 7-1a), will have ampere-turns, equal to:

$$AW = \frac{U_1 w}{R + r}, \qquad (7\text{-}1)$$

where w - the turn number of the winding of relay and r - its resistor/resistance.

Let us substitute into formula for ampere-turns instead of r of its value from (6-12):

$$AW = \frac{U_1 w}{R + Cw^2} \qquad (7\text{-}1a)$$

or

$$AW \cdot Cw^2 - U_1 w + AW \cdot R = 0,$$

whence we obtain for the turn number of the winding of relay, connected in series with the resistor/resistance:

$$w=\frac{U_1\pm\sqrt{U_1^2-4AW\cdot CR}}{2AW\cdot C}=\frac{U_1}{2AW\cdot C}\pm\sqrt{\left(\frac{U_1}{2AW\cdot C}\right)^2-\frac{R}{C}}. \quad (7\text{-}2)$$

This expression gives two values for the turn number of winding, which ensure obtaining the assigned ampere-turns.

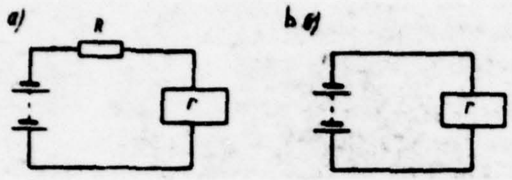


Fig. 7-1. Circuit diagrams of the relay: a) consecutively with resistor/resistance; b) in local circuit.

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Depending on operating conditions, is selected one or the other value for a turn number. If relay must long be located for current, then for the purpose of the savings of energy of battery one should select the first solution (larger turn number). In the case when relay according to the conditions of diagram must have low diresistor/resistance or small inductance, it is necessary to stop at the second solution. When selecting of winding, one should also consider the considerably larger cost/value of fine/thin wire (by diameter 0.05-0.09 mm).

First solution to equation (7-2) frequently gives so

considerable turn number which cannot be virtually carried out this winding due to the very small wire diameter. On the other hand, the second solution sometimes ives the very small turn number, calling too great a current drain or unacceptable due to small inductance of winding. In such cases it is necessary to design the winding of relay, on the basis of the smallest permissible wire diameter, or to conduct calculation for minimum filling of the winding space cf coil.

According to technological considerations it is undesirable to apply wire by diameter it is less than 0.10 mm, but if necessary it is necessary to also use wire with diameter to 0.07 mm, and in the special cases - even to 0.05 mm.

During calculation for the assigned wire diameter, the turn number of winding, obviously, will be less than calculated, but working ampere turns those more assigned, i.e., the safety factor for function will be more than previously accepted.

The calculation of the windings of relay with the aid of formula (7-2) must be conducted by the method successive

conducting of, since value C depends on duty factor $k_3$, value of which during calculation it is necessary to be given tentatively.

Therefore after the preliminary determination of the turn number of the winding of relay, one should select the wire diameter and check the value of duty factor $k_3$. If the obtained value $k_3$ will noticeably differ from that which was accepted at first, then in the case of the need of obtaining the accurate results it is necessary to assign another closer value $k_3$ and to repeat calculation again. The need for repeating calculation during the unsuccessful selection of coefficient of filling is a deficiency/lack in the given above calculation method; however, all formulas, proposed up to now for the expression of duty factor as functions of the wire diameter, proved to be suitable only within very narrow limits.

Knowing the turn number of the winding of relay and the basic dimensions of coil, it is possible to easily determine diameter of wire and the actual value of winding impedance.

If relay is included in local circuit, it is direct

to battery ($R = 0$) (Fig. 7-1b), then the turn number of the winding of this relay will be equal to:

$$w=\frac{U_1}{AW\cdot C}. \quad (7\text{-}3)$$

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Substituting in latter expression for w and C of their value, we obtain formula for determining the wire diameter:

$$d=2\sqrt{\frac{AW\cdot\rho\,(D_0+h)}{U\cdot 10^8}}. \quad (7\text{-}3a)$$

b) calculation for maximum ampere-turns.

For determining the conditions by which the relay will have in the assigned diagram maximum ampere-turns, let us differentiate of expression (7-1a) in terms of turn number and will equate it with zero:

$$\frac{dAW}{dw}=U_1\frac{R+Cw^2-2Cw}{(R+Cw^2)^2}=0$$

either

$$R + Cw^2 - 2Cw^2 = 0,$$

whence we find the condition by which the relay will obtain the maximum ampere-turns:

$$R = Cw^2 \text{ or } R = r. \qquad (7\text{-}4)$$

Turn number of the winding of relay during calculation for the maximum ampere turns

$$w = \sqrt{\frac{R}{C}}. \qquad (7\text{-}5)$$

Substituting in equation (7-1a) instead of r and w of their value, we obtain expression for the maximum number of ampere-turns:

$$AW_{\text{макс}} = \frac{U_1\sqrt{\frac{R}{C}}}{R+R} = \frac{U_1}{2\sqrt{RC}}. \qquad (7\text{-}6)$$

Since in this case winding impedance known, turn number can be found without translation. From formula (6-7) we find:

$$c_0 = \frac{R}{lh(D_0+h)}.$$

Through value $c_0$, we find from table 6-1 or 6-2 corresponding diameters of wire, value $w_0$ and $k_3$ we determine the turn number of winding.

c) the calculation of relay for maximum external resistor/resistance.

From equation for ampere-turns (7-1a) we find expression for the external resistor/resistance:

$$R = \frac{U_1 w - AW \cdot C w^2}{AW}.$$

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For determining the conditions under which external resistor/resistance will be maximum, let us take derivative of this expression in terms of turn number let us equate it with zero:

$$\frac{dR}{dw} = \frac{1}{AW}(U_1 - 2AW \cdot Cw) = 0$$

or

$$U_1 - 2AW \cdot Cw = 0,$$

whence we find the condition under which external resistor/resistance will be maximum:

$$w = \frac{U_1}{2AW \cdot C}. \qquad (7\text{-}7)$$

Substituting in **this expression for w and C of their** value, we obtain:

$$\frac{4k_2 lh}{\pi d^2} = \frac{Ulhk_2 \cdot 10^9}{2AW\pi\rho\,(D_0 + h)},$$

whence we find formula for determining the wire diameter:

$$d = \sqrt{\frac{8AW \cdot \rho \cdot 10^{-9}(D_0 + h)}{U}}. \qquad (7\text{-}8)$$

Substituting in equation for R instead of w its value from formula (7-7), we will obtain expression for the maximum external resistor/resistance:

$$R_{\text{макс}} = \frac{\frac{U_1^2}{2AW \cdot C} - \frac{U_1^2}{4AW \cdot C}}{AW} = \frac{U_1^2}{4AW^2 C}. \qquad (7\text{-}9)$$

Winding impedance of relay according to (6-12) is equal to:

$$r = Cw^2 = \frac{CU_1^2}{4AW^2C^2} = \frac{U_1^2}{4AW^2C}.$$

Consequently, in the case of maximum external resistor/resistance will also occur the equality:

$$R_{\text{внеш}} = r.$$

During differentiation of formulas for AW and R, we considered coefficient of C as constant, not depending on turn number. Actually value C is a function of turn number, since duty factor depends on the wire diameter. Therefore actual condition for maximum AW and R differs somewhat from expression (7-4) and depends on the wire diameter. For the most frequently used diameters of the wire (0.10-0.20 m) of the brand PEL, maximum AW and R will be under the condition:

$$r = (0{,}82 \div 0{,}90)R.$$

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However, the curve of the dependence of a change in the ampere-turns on winding impedance near maximum has small curvature; therefore in the majority of cases, we will not make a noticeable error, if we are consider condition for a maximum equation (7-4).

7-3. Calculation of the relay, connected in series with resistor/resistance, for the minimum consumption of copper.

When according to circuit conditions the value of resistor/resistance or inductance does not have special limitations, it is necessary to design the windings of relay for the minimum consumption of copper, i.e., for minimum filling of the winding space of coil with the assigned ampere-turns.

For minimum filling of the winding space of coil, one should design also the first windings of multiwound coils.

Substituting in expression (7-1a) instead of r and C

of their value from formulas (6-12) and (6-13), we obtain:

$$AW=\frac{U_1w}{R+\frac{\pi\rho\cdot10^{-8}}{lhk_3}(D_0+h)w^2}=\frac{U_1w}{R+B\frac{D_0+h}{h}w^2},$$

or

$$AW\cdot Rh+AW\cdot BD_0w^2+AW\cdot Bhw^2-U_1wh=0,$$

where

$$B=\frac{\pi\rho\cdot10^{-8}}{lk_3}.$$

Hence we find:

$$h=\frac{AW\cdot BD_0w^2}{U_1w-AW\cdot Bw^2-AW\cdot R}.$$

For determining the minimum height/altitude of winding/coil with the assigned ampere-turns, let us differentiate of h in terms of w and equate it with zero:

$$\frac{dh}{dw}=AW\cdot BD_0\frac{2w(U_1w-AW\cdot Bw^2-AW\cdot R)-w^2(U_1-2AW\cdot Bw)}{(U_1w-AW\cdot Bw^2-AW\cdot R)^2}=0$$

or

$$U_1w-2AW\cdot R=0.$$

From last/latter equation we obtain expression for the turn number of relay, with minimum filling of the winding space of the coil:

$$w = \frac{2AW \cdot R}{U_1}. \quad (7\text{-}10)$$

On the other hand, from formulas (7-1)

$$w = \frac{AW(R+r)}{U_1}.$$

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Consequently, during the calculation of the winding of relay for the minimum consumption of copper must be:

$$r = R.$$

The minimum height/altitude of the winding of relay let us find, substituting in expression (6-14) instead of w its value from (7-10):

$$h_{мин} = \frac{D_0}{\frac{U_1^2 l k_з \cdot 10^3}{4AW^2 R \pi \rho} - 1}. \quad (7\text{-}11)$$

Value $k_з$ during calculation it is necessary to be

given tentatively.

7-4. Calculation of the relay, connected in compound circuit.

a) calculation for filling of entire winding space of coil.

Calculation for the assigned ampere-turns.

Majority compound circuits, which are encountered during the design of the installations of automation, telemechanics and communication/connections, can be easily led to the circuit, depicted to Fig. 7-2a.

On the basis of the Ohm's laws and Kirchhoff, let us find the ampere-turns which will obtain relay with the smallest operating voltage of the battery:

$$AW = \frac{U_1 w}{\frac{R}{r_m}(r_m + r_d + r) + r + r_d}. \qquad (7\text{-}12)$$

Substituting in expression for ampere-turns instead of r its value from equation (6-12), we will obtain:

$$AW = \frac{U_1 w}{\frac{R}{r_m}(r_m + r_d + Cw^2) + r_d + Cw^2}$$

or

$$AW \cdot C\left(1 + \frac{R}{r_m}\right)w^2 - U_1 w + AW\left[R\left(1 + \frac{r_d}{r_m}\right) + r_d\right] = 0.$$

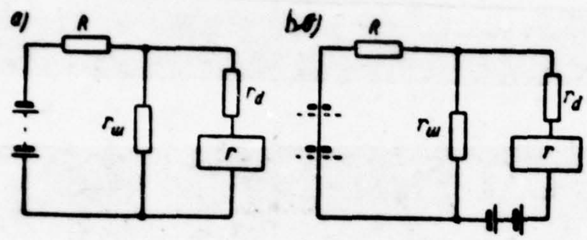


**Fig. 7-2. Circuit diagrams of the** relay: a) in compound circuit; b) in compound circuit during the conditional transference of battery.

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We hence obtain formula for determining the turn number of the winding of relay, working in the compound circuit:

$$w = \frac{U_1 \pm \sqrt{U_1^2 - 4AW^2C\left[R\left(1+\frac{r_d}{r_w}\right)+r_d\right]\left(1+\frac{R}{r_w}\right)}}{2AW\cdot C\left(1+\frac{R}{r_w}\right)}. \quad (7\text{-}13)$$

Calculation for maximum ampere-turns.

We convert expression (7-12) for the ampere-turns:

$$AW = \frac{U_1 r_m w}{(R + r_m) C w^2 + R (r_m + r_d) + r_m r_d}.$$

For determining the conditions by which the relay will obtain maximum ampere-turns, let us differentiate of expression for ampere-turns in terms of w and will equate it with zero; we will obtain:

$$\frac{dAW}{dw} = U_l r_m \frac{(R + r_m) C w^2 + R (r_m + r_d) + + r_m r_d - 2 C w^2 (R + r_m)}{[(R + r_m) C w^2 + R (r_m + r_d) + r_m r_d]^2} = 0$$

or

$$R (r_m + r_d) + r_m r_d - (R + r_m) C w^2 = 0,$$

whence we find the formula for winding impedance, which ensures obtaining of maximum ampere-turns in the assigned circuit:

$$r = \frac{R (r_m + r_d) + r_m r_d}{R + r_m} = r_d + \frac{R r_m}{R + r_m}. \qquad (7\text{-}14)$$

b) calculation for minimum filling of winding space.

With minimum filling of the winding space of the coil of resistance of the winding of relay, must be equal to resistor/resistance, ensuring maximum ampere-turns in this circuit, i.e.,

$$r = r_d + \frac{Rr_m}{R + r_m}.$$

The turn number of the winding of relay, which occupies minimum winding space, will be equal to:

$$\begin{aligned} w &= \frac{AW}{U_1 r_m}[R(r_d + r_m + r) + r_m(r_d + r)] = \\ &= \frac{AW}{U_1 r_m}\left[R\left(2r_d + r_m + \frac{Rr_m}{R + r_m}\right] + r_m\left(2r_d + \frac{Rr_m}{R + r_m}\right)\right]. \quad (7\text{-}15) \end{aligned}$$

The height/altitude of winding is determined with the aid of formula (7.11).

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c) The general method of the calculation of relay, connected in any compound circuit.

For the calculation of relay, connected in more compound circuits to maximum ampere-turns or to the minimum consumption of copper, it is possible to use the reciprocity theorem, from which follows that for the computation of the most favorable resistor/resistance of relay, connected in compound circuit, it is unimportant, in which place is located the current source. For simplification in the calculations to more convenient conditionally transfer battery into that branch of the circuit in which is located by relay (as this shown in the diagram of Fig. 7-2 b).

Consequently, the formula of most advantageous winding

impedance of relay will always take the following form:

$$r = r_d + r_{экв}, \qquad (7\text{-}16)$$

where

$r_d$ - the resistor/resistance, connected in series from relay in the unbranched branch, and

$r_{экв}$ - equivalent resistance of the other as convenient to the complicatedly branched part of the circuit.

For example, for the circuit, given on Fig. 7-2a, equivalent resistance, obviously, is equal to:

$$r_{экв} = \frac{Rr_ш}{R + r_ш}$$

and, therefore,

$$r = r_d + \frac{Rr_ш}{R + r_ш}.$$

Knowing advantageous winding impedance of relay, connected in any compound circuit, it is possible to determine the turn number of this relay.

During the calculation of relay for maximum ampere-turns, the height/altitude of winding/coil is assigned

and turn number can be found with the aid of coefficient $c_0$ and table 6-1 and 6-2.

If calculation is conducted for the minimum consumption of copper, then the turn number of winding is determined from the formula:

$$w = \frac{AW}{i_p}, \quad (7\text{-}17)$$

where $i_p$ the current strength in the winding of relay, calculated with the aid of Ohm and Kirchhoff laws.

7-5. Calculation of the relay, connected in local circuit.

a) Calculation for filling of entire winding space of coil.

For the turn number of the winding of relay, connected in local circuit, we were obtained (7-3):

$$w = \frac{U}{AW \cdot C}.$$

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Substituting in this formula for C and w of their value

from expressions (6-13), (6-3) and (6-4), we find:

$$\frac{4lhk_3}{\pi d^2} = \frac{U_1 lhk_3}{AW \cdot \pi\rho (D_0 + h) \cdot 10^{-8}},$$

whence we obtain formula for determining the diameter of the wire of the winding of relay, connected in the local circuit:

$$d = \sqrt{\frac{4AW \cdot \rho (D_0 + h) \cdot 10^{-8}}{U_1}}. \quad (7\text{-}18)$$

During calculation according to this equation, the wire diameters are obtained by very small.

b) ~~c~~ C alculation for minimum filling of the winding space of coil.

During a decrease in the height/altitude of winding/coil, as is evident from (6-13), the value of coefficient C and the power, consumed by the winding of relay, they increase. Therefore the limit of a decrease in the height/altitude of winding/coil is maximum power $P_m$, permissible in the continuous operation of relay.

The maximum value of coefficient C with the assigned

ampere turns will be equal to:

$$C = \frac{P_m}{AW^2}. \tag{7-19}$$

Substituting in (6-13) instead of C this value from last/latter expression, we obtain:

$$\frac{P_m}{AW^2} = \frac{\pi\rho \cdot 10^{-8}}{lhk_3}(D_0 + h)$$

or

$$\frac{P_m}{AW^2} - \frac{\pi\rho \cdot 10^{-8}}{lk_3} = \frac{D_0\pi\rho \cdot 10^{-8}}{lhk_3},$$

whence we find formula for determining the minimum height/altitude of winding/coil with the assigned ampere-turns:

$$h_{min} = \frac{D_0\pi\rho \cdot 10^{-8}}{\left(\frac{P_m}{AW^2} - \frac{\pi\rho \cdot 10^{-8}}{lk_3}\right) lk_3} = \frac{D_0}{\frac{P_m lk_3}{AW^2 \pi\rho} \cdot 10^{8} - 1}. \tag{7-20}$$

Value $k_3$ during calculation it is necessary to be given tentatively. The wire diameter is calculated with the aid of the formula (7-18) into which instead of h we substitute $h_{min}$. The calculated diameter of wire is rounded off to the nearest nominal value and value $k_3$ is checked using the table of the parameters of wire.

The value of the maximum power, permissible in the continuous operation of relay, decreases with a decrease in the height/altitude of winding, since its cooling external surface in this case decreases.

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Therefore value $P_m$, that which was assigned usually for the nominal altitude of winding, must be decreased during precomputation approximately 2-3 times.

Substituting in formula (7-3) instead of C its value from expression (7-19), we obtain expression for the turn number of winding during calculation for the minimum consumption of copper:

$$w=\frac{U_1}{AW\frac{P_m}{AW^2}}=\frac{U_1 AW}{P_m}. \quad (7\text{-}21)$$

Winding impedance we compute by formula (6-7), substituting for h the actual (minimum) height/altitude of

winding/coil $h_{мин}$.

c) The calculation of the winding of relay with the assigned wire diameter.

During the calculation of the "local" relays, having light load on the minimum consumption of copper, fairly often is obtained a small diameter of the wire of order 0.05-0.06 mm. This fine/thin wire is expensive and insufficiently reliable in winding/coil and in operation; therefore is necessary to apply for coils the wire of high diameter. An increase in the wire diameter against calculated causes an increase in the working ampere-turns.

The working ampere-turns of "local" relay with the assigned wire diameter are determined from formula (7-18):

$$AW = \frac{Ud^2 \cdot 10^3}{4\rho (D_0 + h_1)}, \qquad (7\text{-}22)$$

where $h_1$ - a height/altitude of winding/coil with the assigned wire diameter.

The actual height/altitude of winding/coil, according to

(6-26), will be equal to:

$$h_1 = \frac{w}{lw_0} = \frac{AW \cdot U}{P_m lw_0}.$$

Substituting in expression (7-22) instead of $h_1$ its value, we obtain:

$$AW = \frac{Ud^2 \cdot 10^2}{4\rho\left(D_0 + \frac{AW \cdot U}{P_m lw_0}\right)},$$

whence

$$\frac{U}{P_m lw_0} AW^2 + D_0 AW - \frac{Ud^2 \cdot 10^2}{4\rho} = 0.$$

Solving this equation, we obtain formula for determining the working ampere-turns which it will have local relay during calculation for the assigned wire diameter:

$$AW = P_m lw_0 \frac{-D_0 + \sqrt{D_0^2 + \frac{U^2 d^2 \cdot 10^2}{P_m lw_0 \rho}}}{2U}. \quad (7\text{-}23)$$

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Minus sign before the root we reject/throw, since the

second solution does not have physical sense. Turn number and the height/altitude of winding we determine with the aid of (7-21) and (6-26). Substituting in expression (6-7) the obtained value $h_1$, we find winding impedance.

7-6. Calculation of two relays, connected in series with resistor/resistance (Fig. 7-3).

a) Calculation for filling of entire winding space of coil.

Let us examine the most complex case when both relays have different loads and different winding spaces (different coils). Let us designate working ampere-turns, turn number and winding impedance of both relays, correspondingly, by $AW_1$, $AW_2$, $w_1$, $r_1$, $w_2$, and $r_2$. With the smallest worker of the voltage of battery $U_1$, the first relay will obtain the ampere-turns:

$$AW_1 = \frac{U_1 w_1}{r_1 + r_2 + R}. \qquad (7\text{-}24)$$

The second relay under these conditions will obtain the ampere-turns:

$$AW_2 = \frac{U_1 w_2}{r_1 + r_2 + R}. \qquad (7\text{-}25)$$

After dividing both these expressions to each other, we obtain the equation, which relates the turn numbers of both relays:

$$\frac{U_1 w_1}{AW_1} = \frac{U_1 w_2}{AW_2},$$

whence

$$w_2 = \frac{AW_2}{AW_1} w_1. \tag{7-26}$$

Winding impedances of both relays are respectively equal to:

$$r_1 = C_1 w_1^2 \overset{(1)}{\text{и}} \; r_2 = C_2 w_2^2.$$

Key: (1). and.

where

$$C_1 = \frac{\pi\rho \cdot 10^{-3}}{l_1 h_1 k_3}(D_{01} + h_1) \overset{(1)}{\text{и}} \; C_2 = \frac{\pi\rho \cdot 10^{-3}}{l_2 h_2 k_3}(D_{02} + h_2).$$

Key: (1). and. 97 After substituting into equation (7-24) instead of $r_1$, $r_2$ and $w_2$ their value of the given above expressions, we will obtain:

$$AW_1 = \frac{U_1 w_1}{C_1 w_1^2 + \frac{AW_2^2}{AW_1^2} C_2 w_1^2 + R} \tag{7-27}$$

or

$$(AW_1^2C_1 + AW_2^2C_2)\,w_1^2 - U_1AW_1w_1 + AW_1^2R = 0,$$

whence we find formula for the turn number of the winding of the first relay:

$$w_1 = AW_1\frac{U_1 \pm \sqrt{U_1^2 - 4R\,(AW_1^2C_1 + AW_2^2C_2)}}{2\,(AW_1^2C_1 + AW_2^2C_2)}. \qquad (7\text{-}28)$$

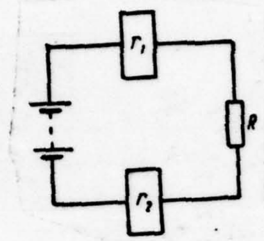


Fig. 7-3. Diagram of series connection of two relays.

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If the series-connected resistor/resistance is equal to zero, then

$$w_1 = \frac{U_1 AW_1}{AW_1^2 C_1 + AW_2^2 C_2}. \tag{7-29}$$

Substituting in (7-26) instead of $w_1$ its value from last/latter expression, let us find the turn number of the winding of the second relay.

If both relays have equal loads and identical coils, then the turn number of each of these relay will be equal to:

$$w_1 = w_2 = \frac{U_1 \pm \sqrt{U_1^2 - 8AW_1^2 RC}}{4AW \cdot C}. \tag{7-30}$$

Calculation for maximum external resistor/resistance.

The maximum value of the external resistor/resistance R with the assigned ampere-turns $AW_1$ and $AW_2$ will occur under the condition:

$$R = r_1 + r_2.$$

Substituting for $r_1$ and $r_2$ their expressions, we obtain:

$$R = C_1 w_1^2 + C_2 w_2^2.$$

Turn number in the windings of both relays, obviously, will be equal to:

$$w_1 = \frac{2AW_1R}{U_1} \stackrel{(1)}{\text{и}} w_2 = \frac{2AW_2R}{U_1}.$$

Key: (1). and.

Substituting in formula for R instead of $w_1$ and $w_2$ of their value, we obtain:

$$R = \frac{4R^2}{U_1^2}(AW_1^2C_1 + AW_2^2C_2).$$

whence we find expression for the maximum resistor/resistance of the line:

$$R_{\text{макс}} = \frac{U_1^2}{4(AW_1^2 C_1 + AW_2^2 C_2)}. \quad (7\text{-}31)$$

Let us substitute into equation for $w_1$ and $w_2$ instead of R its value from formula (7-31). We obtain expression for the turn number of both relays during the calculation of circuit for the maximum external resistor/resistance:

$$w_1 = \frac{U_1 AW_1}{2(AW_1^2 C_1 + AW_2^2 C_2)} \quad (7\text{-}32)$$

and

$$w_2 = \frac{U_1 AW_2}{2(AW_1^2 C_1 + AW_2^2 C_2)}. \quad (7\text{-}33)$$

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b) The calculation of relay for minimum filling of winding space.

If both relays have identical coils, then these relays

it is easy to design for the minimum consumption of copper; otherwise the calculation is feasible, only when is assigned the ratio of coefficients $C_1/C_2$. Minimum filling of the winding space of both relays we will have under the condition:

$$R = r_1 + r_2. \quad (7\text{-}34)$$

turn number in the windings of both relays in this case will be, it is obviously also equal to:

$$w_1 = \frac{2AW_1R}{U_1} \quad (7\text{-}35)$$

and

$$w_2 = \frac{2AW_2R}{U_1}. \quad (7\text{-}36)$$

Winding impedance of these relays

$$r_1 = C_1w_1^2 \text{ и}^{(1)} \ r_2 = C_2w_2^2.$$

Key: (1). and.

The value of coil current of both relays is identical; therefore

$$\frac{r_1}{r_2} = \frac{C_1w_1^2}{C_2w_2^2} = \frac{AW_1^2C_1}{AW_2^2C_2},$$

whence

$$r_2 = r_1 \frac{AW_2^2 C_2}{AW_1^2 C_1}.$$

Substituting the value $r_2$ in formula (7-34), we obtain:

$$R = r_1 \left(1 + \frac{AW_2^2 C_2}{AW_1^2 C_1}\right).$$

We hence find expression for winding impedance of both relays

$$r_1 = \frac{R}{1 + \frac{AW_2^2 C_2}{AW_1^2 C_1}} = R \frac{AW_1^2 C_1}{AW_1^2 C_1 + AW_2^2 C_2} \quad (7\text{-}37)$$

and

$$r_2 = R \frac{AW_2^2 C_2}{AW_1^2 C_1 + AW_2^2 C_2}. \quad (7\text{-}38)$$

During calculation it is necessary to be given the ratio of coefficients $C_1/C_2$.

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7-7. Calculation of two in parallel connected relays, working consecutively with resistor/resistance (Fig. 7-4).

a) the calculation of relay for filling of entire winding space.

Let us examine the case when both relays have different load and different winding spaces. On the basis of the laws of electrical circuit, let us write expressions for the ampere-turns of both relays.

The first relay, with the smallest operating voltage of battery, will obtain the ampere-turns:

$$AW_1 = \frac{U_1 w_1 r_2}{R(r_1 + r_2) + r_1 r_2}. \quad (7\text{-}39)$$

Second relay under the same conditions to obtain:

$$AW_2 = \frac{U_1 w_2 r_1}{R(r_1 + r_2) + r_1 r_2}. \quad (7\text{-}40)$$

Solving together (7-39) and (7-40) and substituting place $r_1$ and $r_2$ of their value, we obtain the equation, which relates the turn numbers of both relays:

$$\frac{U_1 w_1 C_2 w_2^2}{AW_1} = \frac{U_1 w_2 C_1 w_1^2}{AW_2},$$

whence

$$w_2 = \frac{AW_1 C_1}{AW_2 C_2} w_1. \quad (7\text{-}41)$$

Substituting in equation (7-39) instead of $r_1$, $r_2$ and $w_2$ their values, we will obtain:

$$AW_1 = \frac{U_1 w_1 C_2 \frac{AW_1^2 C_1^2}{AW_2^2 C_2^2} w_1^2}{R\left(C_1 w_1^2 + C_2 \frac{AW_1^2 C_1^2}{AW_2^2 C_2^2} w_1^2\right) + C_1 w_1^2 C_2 \frac{AW_1^2 C_1^2}{AW_2^2 C_2^2} w_1^2}$$

or

$$AW_1^2 C_1 w_1^2 - AW_1 C_1 U_1 w_1 + R(AW_1^2 C_1 + AW_2^2 C_2) = 0,$$

whence we find expression for the turn number of the winding of the first relay:

$$w_1 = \frac{U_1 \pm \sqrt{U_1^2 - 4R(AW_1^2 C_1 + AW_2^2 C_2)}}{2AW_1 C_1} \qquad (7\text{-}42)$$

Let us substitute in (7-41) instead of $w_1$ its value from last/latter expression; we obtain the turn number of the winding of the second relay:

$$w_2 = \frac{AW_1 C_1}{AW_2 C_2} w_1.$$

If both relays are identical, then the turn number of the winding of each relay will be equal to:

$$w_1 = w_2 = \frac{U_1 \pm \sqrt{U_1^2 - 8AW^2 CR}}{2AW \cdot C}. \qquad (7\text{-}43)$$

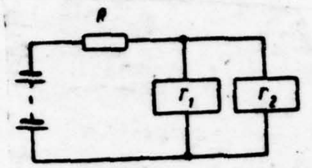


Fig. 7-4. Circuit of parallel connection of two relays.

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b) The calculation of relay for maximum external resistor/resistance.

The maximum value of resistor/resistance R with the assigned ampere-turns $AW_1$ and $AW_2$ will be equal to:

$$R_{\text{макс}} = \frac{r_1 r_2}{r_1 + r_2}. \qquad (7\text{-}44)$$

Substituting in equations (7-39) and (7-40) instead of $(r_1 + r_2)$ their value from last/latter expression, we

obtain:

$$AW_1 = \frac{U_1 w_1}{2r_1} = \frac{U_1}{2C_1 w_1}$$

and

$$AW_2 = \frac{U_1}{2C_2 w_2},$$

whence we find expressions for the turn numbers of both relays during the calculation of circuit for the maximum external resistor/resistance:

$$w_1 = \frac{U_1}{2AW_1C_1} \tag{7-45}$$

and

$$w_2 = \frac{U_1}{2AW_2C_2} \tag{7-46}$$

If we into formula (7-44) substitute for $r_1$ and $r_2$ their value, we obtain expression for the maximum external resistor/resistance:

$$R_{\text{макс}} = \frac{[illegible]}{4(AW_1C_1 + [illegible])} \quad (7\text{-}47)$$

c) The calculation of relay for the minimum consumption of copper.

Minimum filling of winding space will be under the condition:

$$R=\frac{r_1 r_2}{r_1+r_2}.$$

After substituting into the last/latter expression for $r_2$ and $w_2$ of their value, we obtain formulas for winding impedances of both relays:

$$r_1=R\frac{AW_1^2C_1+AW_2^2C_2}{AW_1^2C_1} \qquad (7\text{-}48)$$

and

$$r_2=R\frac{AW_1^2C_1+AW_2^2C_2}{AW_2^2C_2}. \qquad (7\text{-}49)$$

The turn number of the windings of both relays, obviously, will be equal to:

$$w_1=\frac{2AW_1r_1}{U_1}=\frac{2R}{U_1AW_1C_1}(AW_1^2C_1+AW_2^2C_2) \qquad (7\text{-}50)$$

and

$$w_2=\frac{2R}{U_1AW_2C_2}(AW_1^2C_1+AW_2^2C_2). \qquad (7\text{-}51)$$

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Coefficients $C_1$ and $C_2$ contain the unknown values $h_1$

and $h_2$; therefore for calculation it is necessary to assign ratio $C_1/C_2$.

7-8. Calculation of "linear" relays.

"linear" relay is included consecutively with by exchange line R **by subset** $r_a$ and by supplementary resistor/resistance $r_l$ (Fig. 7-5) and works with call by the subscriber of station. Relays must reliably wear/operate through line with maximum resistor/resistance and release through leakage resistance of line $R_y$ after interrupting of the lever/crank contact of apparatus.

Depending on the assigned conditions "linear" relay can be relied on the assigned amper-turns or the maximum resistor/resistance of line.

If assigned great resistor/resistance of line, then the winding of relay is designed for the assigned ampere-turns with the lower limit of the voltage of battery $U_1$ according to formula (7-2):

$$w = \frac{U_1 \pm \sqrt{U_1^2 - 4AW^2C(R + r_a + r_B)}}{2AW \cdot C}. \qquad (7\text{-}52)$$

On the other hand, so that the "linear" relay would release its armature during interrupting of the lever/crank contact of apparatus with the upper limit of the voltage of battery $U_2$, must be observed following condition:

$$AW_{от} \geqslant \frac{U_2 w}{R_у}.$$

The effect of booster resistor/resistance, resistance of the winding of relay and line we disregard.

If the actual ampere-turns of retention, created by circuit, prove to be more than the ampere-turns of the release/tempering of relay, then, so that the relay would release its armature, it is necessary to increase the height of the plug (if this proves to be sufficient) or to decrease the turn number of the winding of relay.

In the latter case the turn number of the winding of "linear" relay it is necessary to convert by the following formula:

$$w' = \frac{AW_{от} R_у}{U_2}. \tag{7-53}$$

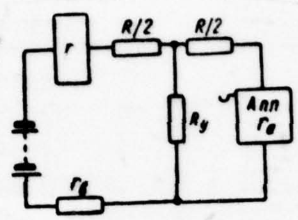


Fig. 7-5. Circuit diagram of line relay.

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If we preserve the selected initially safety factor $K_1$, then the great resistor/resistance of line, through which the relay will work, it decreases to value

$$R = \frac{U_1 w' - AW\,(r_a + r_в)}{AW}. \qquad (7\text{-}54)$$

The maximum resistor/resistance of line with filling of entire winding space of coil will be with the equality of external and internal resistor/resistances (winding impedance of relay); consequently,

$$R + r_a + r_в = r$$

or

$$R_{\text{макс}} = r - r_{\text{a}} - r_{\text{в}}.$$

The turn number, which must have "linear" relay so that it reliably would work through the line of maximum resistor/resistance (with the smallest operating voltage of battery), it is possible to determine from formula (7-7):

$$w = \frac{U_1}{2AW \cdot C}.$$

Calculation according to (7-7) and (7-9) does not frequently give the correct solution of problem, since in the circuits of some commutators "linear" relay together with choke coil is utilized as the battery supply bridge. In such cases the resistor/resistance of exchange line (and of "linear" relay) is limited by the minimum value of the current $I_{\text{мин}}$, of the necessary for a microphone current supply of subscriber.

In this case the turn number of the winding of "linear" relay must be equally to:

$$w = \frac{AW'}{I_{\text{мин}}}. \tag{7-55}$$

Most the resistor/resistance of the exchange line, which ensures the minimum feed current of microphone, will be:

$$R_{\text{макс}} = \frac{U_1}{I_{\text{мин}}} - (r_a + r_b). \qquad (7\text{-}56)$$

7-9. Calculation of "group" relays.

"Group" relay is connected in series with a group of other relays connected together in parallel, signal lamps or resistor/resistances (Fig. 7-6). Let us designate the ampere-turns, necessary for the reliable work of "group" relay, by $AW_1$. During the closing/shorting at least of one of parallel circuits and with smallest operating voltage of battery, "group" relay must actuate/operate. So that the voltage drop across the winding of relay would be minimum, it is necessary its winding to calculate for filling the entire winding space of the coil using formula (7-2) and to select the smaller value of turn number.

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Sometimes "group" relay is connected in series with resistor/resistances; in that case for a decrease in the energy consumption the resistance of this relay it is

desirable to select, on the contrary, largest possible.

A quantity of signal (calling) lamps or relay, operated simultaneously by one "group" relay, is limited, on one hand, to highest efficiency $P_{m}$ permissible in the continuous operation of relay, and on the other hand - by the maximum value of voltage drop $\Delta U_{m}$ on its terminal/grippers.

A voltage drop across of "group" distribution terminal must not exceed 5-10o/o.

The maximum value of coil current of "group" relay with the greatest operating voltage of battery $U_2$ is equal to:

$$I_m = \frac{U_2}{r + \frac{R}{n}} = \frac{U_2 n}{rn + R}, \qquad (7\text{-}57)$$

where n - the number of in parallel connected alarms. A great voltage drop across of "group" distribution terminal will be equal to:

$$\Delta U_m = I_m r = \frac{U_2 nr}{rn + R} \quad \overset{(1)}{\text{или}} \quad U_2 rn - \Delta U_m rn - \Delta U_m R = 0,$$

Key: (1). or.

whence we find expression for the maximum number of

simultaneously included calling signals, operated by one "group" relay:

$$n_m = \frac{\Delta U_m R}{(U_2 - \Delta U_m)\, r}. \qquad (7\text{-}58)$$

7-10. Calculation of the relay, connected in the diagonal of bridge.

In some circuits of automation, the polarized or magnitoelectric relay is included in the diagonal of bridge (Fig. 7-7), consisting of four resistor/resistances, one or two of which they are variables.

In this case the value of coil current of relay can be determined with the aid of the following formula:

$$i_p = \frac{U \dfrac{R_1R_4 - R_2R_3}{(R_1+R_3)(R_2+R_4)}}{r + \dfrac{R_1R_2R_3 + R_2R_3R_4 + R_3R_4R_1 + R_4R_1R_2}{(R_1+R_3)(R_2+R_4)}} = \frac{U_э}{r + R_э}, \qquad (7\text{-}59)$$

where r - winding impedance of relay.

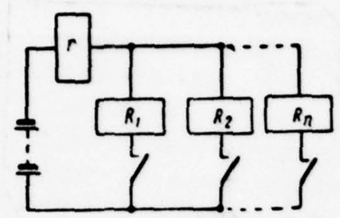


Fig. 7-6. Circuit diagram of group relay.

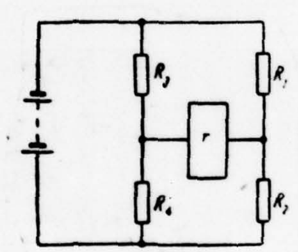


Fig. 7-7. Diagram for connection of relay in diagonal bridge.

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Chapter Eight.

# CALCULATION OF BATTERY SUPPLY RELAYS FOR EXCHANGES.

## 8-1. Calculation of winding of battery supply relay with direct current.

Telephone subset is supplied from the station-type battery through the exchange line and the winding of battery supply relay.

For the decrease in the attenuation, introduced by station-type four-pole, the inductance of battery supply relay at audio frequencies must be sufficiently large, since this relay is included in parallel to speech circuit (Fig. 8-1).

Furthermore, battery supply relay must have two symmetrical in electrical sense windings to avoid the transition of speaking currents of one circuit to another

(adjacent).

On the other hand, the turn number of the winding of battery supply relay is limited to the value of its direct-current resistance, which must be small, for providing the running current of microphone current supply at maximum length of exchange line.

Therefore the magnetic system of battery supply relay must have the largest possible magnetic permeability at audio frequencies.

For loading at audio frequencies, the core of battery supply relay sometimes is manufactured from silicon steel or is supplied with tubes (or plates) made of Permalloy or tranformer steel.

In step-by-step systems of ATS the supply relay simultaneously fulfills the functions of pulse relay, but for simplification in the problem, we will be restricted to examination of this relay only as feeding.

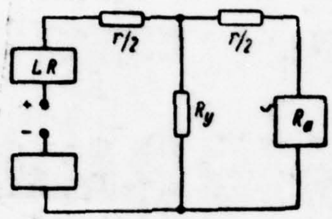


Fig. 8-1. Circuit diagram of battery supply relay.

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For a minimum circuital current of battery supply relay, if we disregard resistance of leakage of line $R_y$, it is possible to write following expression [1-6]:

$$I_{0мин} = \frac{U_1}{r_{макс} + R + R_a}, \quad (8\text{-}1)$$

where $r_{макс}$ — the maximum resistor/resistance of line.

In the extreme case when the resistor/resistance of line can be considered equal to zero, circuital current of relay will be equal to:

$$I_{0макс} = \frac{U_2}{R + R_a}. \quad (8\text{-}2)$$

Greatest and smallest values alternating current component in the circuit:

$$I_{\text{макс}} = I_{0\text{макс}} \frac{r'}{R'_{\text{м}} + R_{\text{н}}} \quad \text{и} \quad I_{\text{мин}} = I_{0\text{мин}} \frac{r''}{R''_{\text{м}} + R_{\text{н}}},$$

Key: (1). and.

where r' and r" - the amplitude of variable composing the resistor/resistances of microphone when $I_{0\text{макс}}$ and $I_{0\text{мин}}$;

$R'_{\text{м}}$ and $R''_{\text{м}}$ are constant component the resistor/resistances of microphone in the dynamic behavior when $I_{0\text{макс}}$ and $I_{0\text{мин}}$;

$R_{\text{н}}$ are a load impedance.

Losses because of reduction in current in the microphone current supply it is possible to express by the attenuation:

$$b = \ln \frac{I_{\text{макс}}}{I_{\text{мин}}} = \ln \frac{I_{0\text{макс}} r' (R''_{\text{м}} + R_{\text{н}})}{I_{0\text{мин}} (R'_{\text{м}} + R_{\text{н}}) r''} = \ln \frac{I_{0\text{макс}}}{I_{0\text{мин}}} \alpha, \qquad (8\text{-}3)$$

where $\alpha$ is the coefficient, depending on the electrical, acoustic and mechanical parameters of microphone. For high

quality microphones value $\alpha$ it is equal approximately 0.45.

The magnitude of losses of feed is allow/assumed tentatively 0.25-0.3 np.

From equation (8-3) we find:

$$I_{0\,\text{мин}} = \frac{I_{0\,\text{макс}}}{e^b}\alpha = \frac{U_s\alpha}{(R_a+R)\,e^b}. \qquad (8\text{-}4)$$

During the maximum resistor/resistance of line, the battery supply relay must wear/operate with the coefficient cf reserve $K_1$; the ampere-turns of battery supply relay in this case will be equal to:

$$AW_1 = AW_c K_1 = I_{0\,\text{мин}} w \frac{U_s\alpha}{(R_a+R)\,e^b} w = \frac{U_s\alpha w}{(R_a + C_1 w^2)\,e^b}$$

or

$$AW_1 e^b C_1 w^2 - U_s\alpha w + AW_1 e^b R_a = 0,$$

whence we find expression for the calculation of the turn number of the battery supply relay:

$$w = \frac{U_s\alpha \pm \sqrt{U_s^2\alpha^2 - 4AW_1^2 e^{2b} C_1 R_a}}{2AW_1 e^b C_1}. \qquad (8\text{-}5)$$

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The maximum resistor/resistance of line we find,

equalizing equations (8-1) and (8-4); we obtain:

$$r_{\text{макс}} = \left(\frac{U_1 e^b}{U_2 a} - 1\right)(R_a + R). \tag{8-6}$$

If we assign values $\alpha$ = 0.45, b = 0.3 and $U_1/U_2$ = 0.82, then expressions for the turn number of battery supply relay and maximum value of the resistor/resistance of line we will obtain in the following form:

$$w = \frac{U_2 \pm \sqrt{U_2^2 - 36.4W_1^2C_1R_a}}{6.4W_1C_1} \quad \text{и}^{(1)} \quad r_{\text{макс}} = 1{,}46(R_a + R).$$

Key: (1). and.

During the very low resistor/resistance of battery supply relay, sometimes are applied special ballast resistors for the limitation of the maximum strength of feeding current to avoid the overloading of microphones at short exchange lines.

For determining the attenuation, introduced by battery supply relay into speech circuit, it is necessary to calculate inductance and the effective resistance of this relay with alternating current of audio frequency.

## 8-2. Inductance of relay with alternating current.

With the feed of relay by alternating current magnetic flux in massive steel core due to screening effect of eddy currents is forced to the surface of core. Therefore the inductance of coils with steel core with alternating current is less than with constant. The value of the inductance of relay at alternating current depends on the material of core, its form and frequency of the feeding current.

For determining the inductance of relay with alternating current, it is possible to use the given above formula for inductance with direct current, if we in this case into expression for $R_m$ instead of $\mu$ we place average/mean effective permeability of steel $\mu_1$.

The average/mean effective permeability of steel of the magnetic circuit of the relay, prepared from sheet material, can be determined from following expression [8-2]:

$$\mu_1 = \frac{\mu}{p_1} \cdot \frac{\mathrm{sh}\, p_1 + \sin p_1}{\mathrm{ch}\, p_1 + \cos p_1} = A_1 \mu,$$

where

$$A_1 = \frac{1}{p_1} \cdot \frac{\mathrm{sh}\, p_1 + \sin p_1}{\mathrm{ch}\, p_1 + \cos p_1} \qquad (8\text{-}7)$$

and

$$p_1 = \Delta k = \Delta \sqrt{\frac{\omega\mu\mu_0\gamma_1}{2}}. \qquad (8\text{-}8)$$

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Here $\Delta$ - thickness of sheet they stopped, $\mu$ - magnetic permeability of material, $\gamma_1$ - the specific conductivity of the material of core and f - frequency of alternating current.

Inductance of relay depending on turn number, as is known, is expressed by the formula:

$$L = Kw^2,$$

where

$$K = \frac{1}{R'_M}.$$

$R'_M$ is the given effective reluctance of relay.

The resistor/resistance of losses in steel can be presented as follows:

$$r_M = \omega L \frac{\operatorname{sh} p_1 - \sin p_1}{\operatorname{sh} p_1 + \sin p_1} = C_2 w^2.$$

where

$$C_2 = \omega K \frac{\mathrm{sh}\, p_1 - \sin p_1}{\mathrm{sh}\, p_1 + \sin p_1} = \\ = B_1 \omega K. \qquad (8\text{-}9)$$

The effective resistance of relay is made up of resistance of the coil to direct current and the resistor/resistance of the losses

$$R = r + r_м = C_1 w^2 + C_2 w^2 = \\ = C w^2.$$

The computation of coefficients $A_1$ and $B_1$ requires sufficiently much time; therefore for the facilitation of calculations Fig. 8-2 gives the curves of the dependences of these coefficients on value $p_1$.

For the computation of the effective permeability of steel of the magnetic circuit of relay, prepared from the material of round cross-section, it is possible to use expression [8-2]:

$$\mu_1' = \frac{2\mu}{p_2} \cdot \frac{\mathrm{ber}\, p_2\, \mathrm{ber}'\, p_2 - \mathrm{bei}\, p_2\, \mathrm{bei}'\, p_2}{\mathrm{ber}^2\, p_2 + \mathrm{bei}^2\, p_2} = A_2 \mu. \qquad (8\text{-}10)$$

Value of coefficient $C_2$ for relay with core of round cross section will be equal to:

$$C_2 = \omega K \frac{\operatorname{ber} p_2 \operatorname{ber}' p_2 + \operatorname{bei} p_2 \operatorname{bei}' p_2}{\operatorname{ber} p_2 \operatorname{bei}' p_2 - \operatorname{bei} p_2 \operatorname{ber}' p_2} = B_2 \omega K, \qquad (8\text{-}11)$$

where

$$p_2 = \frac{d}{2} \sqrt{\omega \mu \mu_0 \gamma_2}.$$

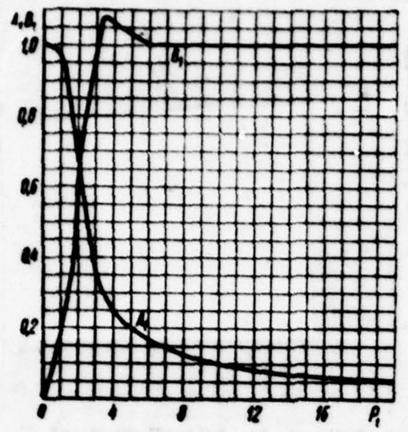


Fig. 8-2. Curves of coefficients $A_1$ and $B_1$.

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The curves of the dependences of coefficients $A_2$ and $B_2$ on value $p_2$ are given in Fig. 8-3.

With value $p_2$, which exceeds 21, one should use the following approximation formula:

$$A_2 = \frac{\sqrt{2}}{p_2}. \quad (8\text{-}12)$$

The given above formulas for the calculation of inductance and effective resistance of relay with alternating

current give more or less accurate results only with small inductions and the small thickness ratios of the material of the core when the value of magnetic permeability at the different points of section can be considered constant.

Such conditions we have, in particular, for the telephone battery supply relay.

For loading with sound frequencies the cores of throttle/chokes, recoil and battery supply relays of the type 100 earlier were manufactured from circular silicon steel (about 4o/o Si) with diameter 8 mm, having initial permeability of approximately 300 and the increased resistivity ($\rho_м \approx$ 4.8•10⁻⁷ Ω•m). However, this solution of problem it is not possible to consider satisfactory for following reasons.

From the theory of distribution of alternating/variable magnetic flux over the section of core [8-1], it is known that absorption of the electromagnetic wave, which penetrates into metal, is determined by factor $e^{-kx}$, where x - the extent of the movement of wave in m and

$$k=\sqrt{\frac{\omega\mu\mu_0\gamma_1}{2}}. \quad (8\text{-}13)$$

Virtually it is possible to consider waves absorbed, when their amplitude decreases to 5o/o of initial value, i.e., when

$$e^{-kx} = 0,05,$$

whence we obtain the following expression for the depth of penetration of alternating/variable magnetic flux into the metal:

$$x = \frac{1}{k} \ln \frac{1}{0,05} = \frac{2,99}{k} = \frac{4,22}{\sqrt{\omega \mu \mu_0 \gamma_1}}. \qquad (8\text{-}14)$$

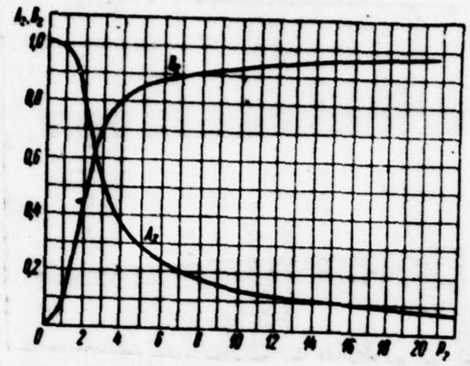

Fig. 8-3. Curved of coefficients $A_2$ and $B_2$.

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For mild transformer steel of the brand E or EA, from which are manufactured the cores of relay in low magnetic fields, it is possible to count $\mu_a$ = 200 and $\gamma_1 = \frac{1}{\rho_{ж}} = 1 \cdot 10^7$ S/m. For silicon steel respectively $\mu_a = 300$ and $\gamma_1 = 2 \cdot 10^6$ S/m. Dependence curves of the depth of penetration of alternating/variable magnetic flux in cores made of silicon and mild steel of brand E from frequency are given in Fig. 8-4. From these curves it follows that at average audio frequency 1000 Hz variable magnetic flux into core

made of massive silicon steel penetrates virtually at depth not greater than 2 mm, the core made of steel of brand E at depth of approximately 1 mm. Therefore it is possible to obtain larger effect, if the core of relay is prepared not from silicon steel, but made of usual steel of brand E or EA above it to place several cut along the length tubes (in the case of the flat/plane core of plates) of sheet tranformer steel or Permalloy by thickness 0.35 mm.

The inductance of relay with tubes is more uniform and less it depends on the strength of magnetizing current, since constant magnetic flux passes, mainly, along basic section of the core of relay.

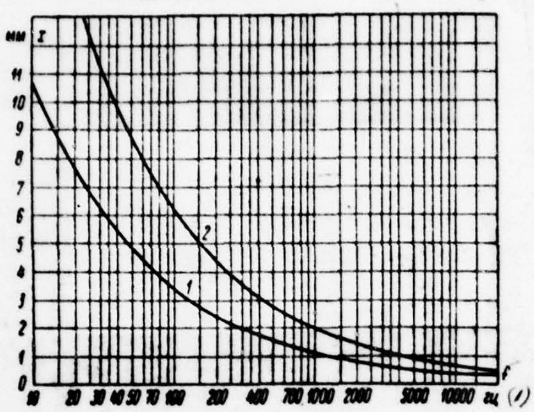


Fig. 8-4. Dependence curves of depth of penetration of alternating/variable magnetic flux into core from frequency in weak fields. 1 - core from the flock of brand E; 2 - core made of silicon steel.

Key: (1) Hz.

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8-3. Calculation of the winding of supply relay with alternating current.

Total resistor/resistance of relay, as is known, is

equal to [1-15]:

$$Z=\sqrt{R^2+\omega^2L^2}=\sqrt{C^2+\omega^2K^2}\cdot w^2.$$

The value impedance which must have battery supply relay in order to ensure the specific attenuation of speaking currents, usually it is assigned.

Therefore from last/latter expression it is possible to obtain formula for the calculation of the winding of battery supply relay with alternating current:

$$w=\sqrt{\frac{Z}{\sqrt{C^2+\omega^2K^2}}}.$$

The turn number, obtained from this formula, must be checked with direct current (8-5) in order to ensure the ampere-turns of the function of relay at the maximum length of exchange line.

8-4. Curves for the calculation of inductance standard relay.

Inductance and effective resistance at the audio frequencies of the normal relay, working without magnetic

biasing, can be calculated with the aid of the given above formulas. During the use of tubes (or plates) and in the presence of magnetic biasing by direct current the analytical method of the calculation of relay very becomes complicated. Therefore in such cases for the calculation of inductance and effective resistance of standard relays, are most better used experimental data.

Figures 8-5 gives the curves of the dependences of coefficients K and C on the magnetizing ampere-turns for relay of the type RPN at frequency 1000 Hz and in variable field of approximately 0.05-0.10 A/cm. From these curves it follows that application/use of four plates (by size/dimension 4 x 10 x 0.35 mm) made of transformer steel of brand E-46 (VP-2), arrange/located on two from each side of the core of relay under winding, gives increase of inductance approximately 2.5 times in the presence of magnetic biasing within limits from 0 to 300 ampere-turns.

The curves of the dependences of coefficients K and C on frequency with the different magnetizing ampere-turns are given in Fig. 8-6.

From these curves it follows that the dependence of

inductance and effective resistance of relay on frequency on logarithmic scale differs little from straight line.

Similar curves for the relay of types RKN, RKM-1, RKMP, RS-52, RMU, RS-13 and RSM are given in Fig. 8-7, 8-8, 8-9 and 8-10.

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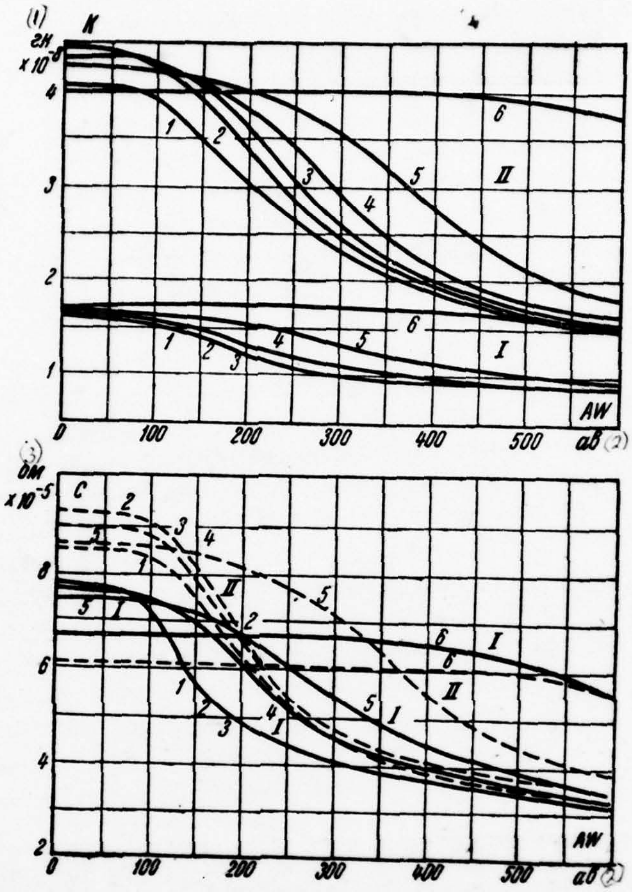


Fig. 8-5. Curves of dependences of coefficients K and C on magnetizing ampere-turns for relay of type RPN. I - a normal relay of the type RPN; II - relay of the type RPN with four plates made of transformer steel with thickness 0.35 mm. The thickness of nonmagnetic antistick strip: 1 - 0.1 mm; 2 - 0.3 mm; 3 - 0.5 mm; 4 - 1.0 mm; 5 - 3.0 mm and 6 - armature is removed.

Key: (1) H. (2) ampere-turns. (3) Ω.

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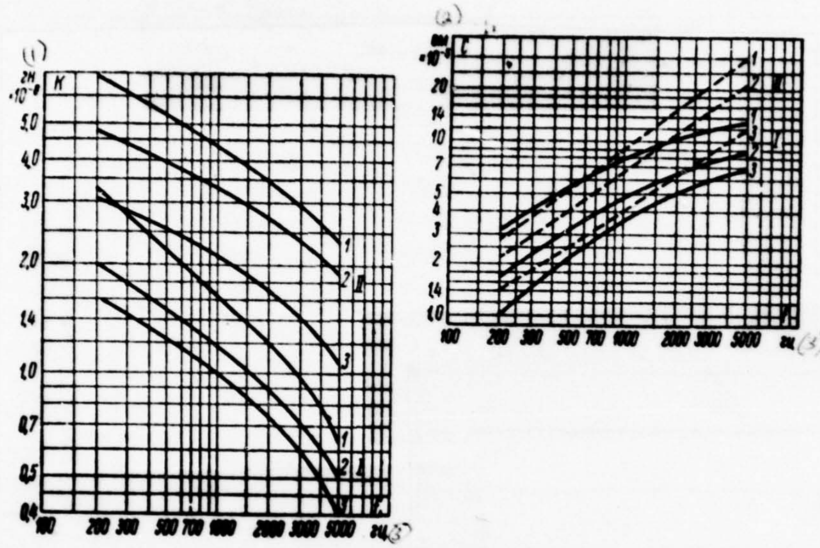


Fig. 8-6. Frequency characteristics of relay of type RPN. I - a normal relay of the type RPN; II - relay of the type RPN with four plates made of transformer steel. 1 - magnetic biasing AW = 0; 2 - magnetic biasing AW = 200 at; 3 - magnetic biasing AW = 400 at.

Key: (1) H. (2) Ω. (3) Hz.

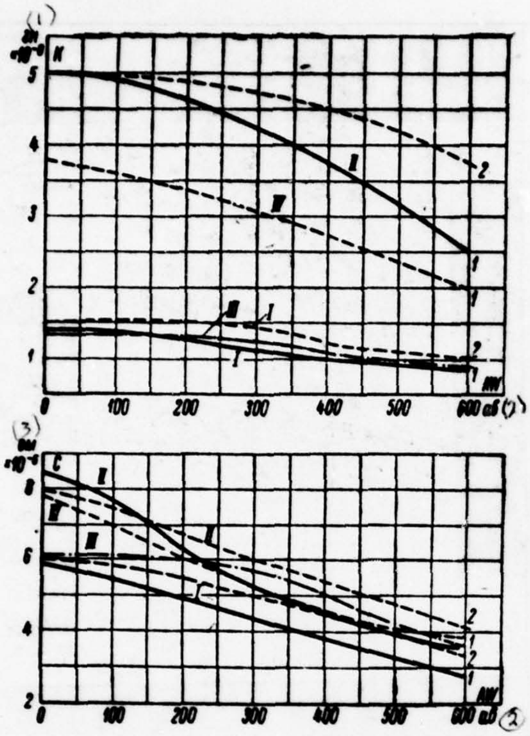


Fig. 8-7. Curved of dependences of coefficients K and C on magnetizing ampere-turns for relay of types RKN and RKM-1 (f = 1000 Hz). I - a normal relay of the type RKN; II - relay of the type RKN from two tubes from Permalloy of brand 50NXC on core; III - a normal relay of type RKM-1; IV are a relay of type RKM-1 with one tube of Permalloy. 1 - armature normal; 2 - armature with grooves (pulse relay).

Key: (1) H. (2) ampere-turns. (3) Ω.

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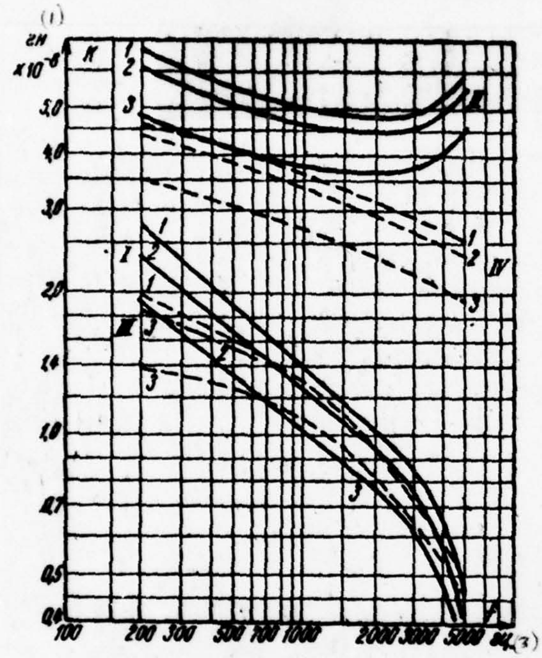


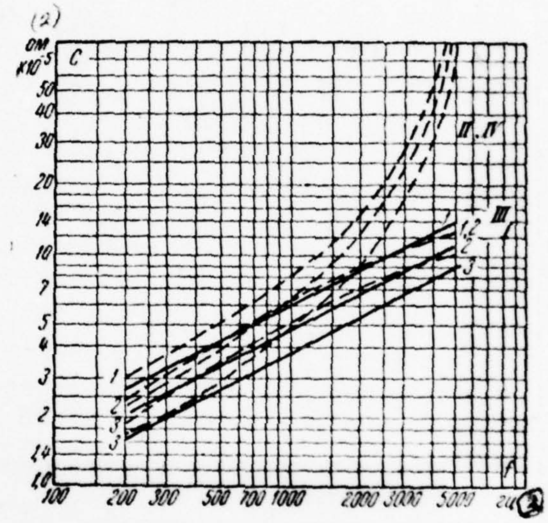


Fig. 8-8. Frequency characteristics of relay of types RKN, RKM-1. I - a normal relay of the type RKN; II - relay of the type RKN with two tubes from Permalloy; III - a normal relay of type RKM-1; IV are a relay of type RKM-1 with one tube of Permalloy. 1 - magnetic biasing AW = 0; 2 - magnetic biasing AW = 200 at; 3 - magnetic biasing AW = 400 at.

Key: (1) H. (2) Ω. (3) Hz.

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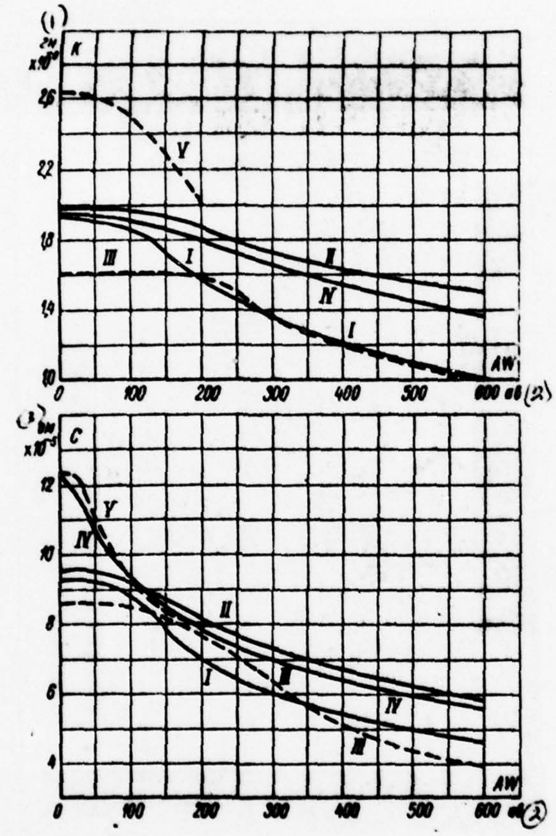


Fig. 8-9. Curved of dependences of coefficients K and C on magnetizing ampere-turns for relay of types RKMP, RS-52, RS-13, RMU and RSM (f = 1000 Hz). I - relay of the type RKMP; II - relay of the type RS-52; III - relay of type RS-1~~M~~3; IV are a relay of the type RMU; V - relay of the type RSM.

Key: (1) H. (2) ampere-turns. (3) Ω.

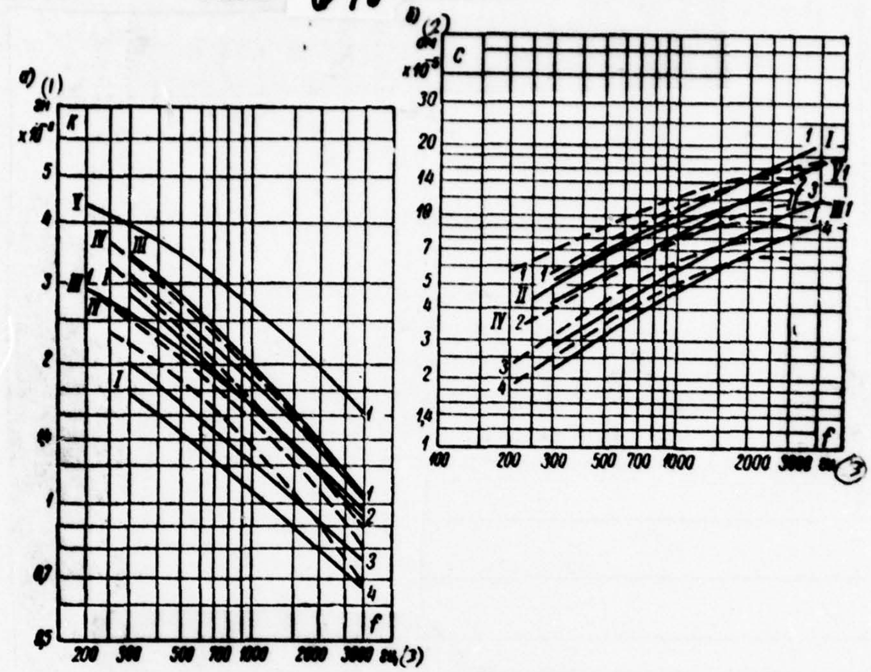


Fig. 8-10. Frequency characteristics of the relay of types RKMP, RS-52, RS-13, RMU and RSM. I - relay of the type RKMP; II - relay of the type RS-52; III - relay of the type RS-13; IV are a relay of the type RMU; V - relay of the type RSM. 1 - magnetic biasing AW = 0; 2 - magnetic biasing AW = 200 at; 3 magnetic biasing AW = 400 at; 4 - magnetic biasing AW = 600 at.

Key: (1) H. (2) Ω. (3) Hz.

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8-5. Inductance of relay with quadrature winding.

During interrupting of the circuits, which feed the windings of relay (possessing inductance), appears the spark discharge, which strongly destroys governing contacts and which threatens by the blast of gas in the shaft/mines, equipped with equipment for automation and communication/connections.

For a decrease in the inductance of the winding of relay (with alternating current) by its core under winding in its entire length usually is placed quadrature winding or tube of red copper. (In certain cases a decrease in the inductance is achieved by the shunting of the winding by semiconductor devices or condenser/capacitors.

The effect of quadrature winding cn the value of the inductance of relay is determined very by many factors and cannot be expressed analytically by sufficiently precise for practical calculations by formulas.

Due to the absence of theoretical and experimental materials for the calculation of the most advantageous size/dimensions of quadrature winding usually for a decrease in the inductance they try to apply quadrature winding of the largest possible height/altitude (thickness). However, this often gives by no means best results.

Figures 8-11 gives the curves of the dependences of coefficients K and C on the height/altitude of the test (nonshorted) section of the winding of relay of the type RKN at the different values of the height/altitude of quadrature winding and frequency 1000 Hz. For a comparison are shown also the curves of coefficients K and C for a normal relay of the type RKN (with Getinaks side), not having quadrature winding ($h_{\text{кв}} = 0$).

From the curves of Fig. 8-11, it follows that the inductance of relay depends not only cn the height/altitude of quadrature winding, but also on the height/altitude of

the test (nonshorted) section of the winding.

The smallest value of coefficient K (and, therefore, smallest inductance) will have relay of the type RKN with quadrature winding by height 1.2 mm at the height/altitude of the test (nonshorted) section of the winding of approximately 0.8-1 mm. Consequently, for obtaining minimum inductance both windings of relay must have common/general/total height 2-2.2 mm instead of the normal height 7.6 mm.

The ratio of the optimum height of quadrature winding to the diameter of core of relay is equal to 0.133. However, at the low altitude of the test section of the winding, its direct-current resistance is obtained by the relatively very large that hardly ever admissible according to work conditions of relay in circuit. Therefore in many instances is necessary to accept the height/altitude of the test section of the winding considerably greater optimum 0.8-1.0 mm.

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With an increase in altitude of test section about from 1

to 7 mm the value of coefficient K increases approximately 2.6 times. An increase in coefficient K with the height/altitude of the test section of the winding is explained by an increase in the mean diameter of winding.

Figures 8-11a, for a comparison shows by dotted line the curve of the dependence of coefficient K of coil without steel core (having the size/dimensions of the winding of relay of the type RKN) on the height/altitude of winding, designed with the aid of formula (4-53). This curve has much the same angle of the slope toward the axis of abscissas as the remaining curves of K for relay with short-circuit windings.

It is interesting that the value of coefficient K for normal relay ($h_{кв}$ = 0), on the contrary, decreases with an increase in altitude of the winding of relay. Is explained this, apparently, by the effect of the self-capacitance of winding of relay, total number of turns of which of tested relay was sufficiently great: 35000.

From the given curves it follows that the inductance of relay of the type RKN at frequency 1000 Hz can be decreased with the aid of quadrature winding approximately

AD-A066 135 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 9/1
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20 times at the height/altitude of the test section of winding h = 0.8-1 mm and only 6 times with h = 7 mm.

It is necessary to note that the given in Fig. 8-11 curves of coefficients K and C are tentative, since the absolute values of these coefficients can change at the different specimen/samples of relay within sufficiently wide limits. The reasons for such oscillation/vibrations are not accurately establish/installed, but they, apparently, are explained by the fluctuations of values of the reversible permeability of steel of core, by the effect of the turn number of inducing winding and by the thickness of the insulation between working and quadrature windings. From this viewpoint, more uniform results, apparently, must give relay with pure copper tubes.

Figures 8-12 gives the curves of the dependences of coefficients K and C on the height/altitude of inducing winding of time-lag relay of the type RKN with pure copper tube with diameter 15/9 mm (the wall thickness of the tube 3 mm) and length 70 mm (at frequency 1000 Hz). Inducing winding of relay was divided along the height (to number of turns ) into five equal parts (sections), inductance was measured consecutively at the height/altitudes of winding

0.75; 1.5; 2.25; 3.0 and 3.75 mm.

In Fig. 8-12 are plotted also by dotted line with the crosses of the value of coefficients of k and C of each of five armature coils individually. These crosses are connected between themselves for clarity the stepped dotted lines, which indicate that within the limits of each section coefficients K and C have constant (average) value.

From curves, shown in figure, it follows that a relay of the type RKN with the copper tube with diameter 15/9 mm (wall thickness 3 mm) has approximately the same values of coefficient K as of relays of this same type with short-circuit winding of similar height (3 mm), from wire with diameter 0.10 mm, the brand PEL. in this case, the value of coefficient K of relay with the copper tube with diameter 15/9 mm (wall thickness 3 mm) has approximately the same values of coefficient of K as of relays this same of type with quadrature winding of analogous height (3 mm), from wire as diameter 0.10 mm, the brand PEL. In this case, the value of coefficient K of relay with the copper tube with diameter 15/9 mm is approximately 1.5 times more than in relay with quadrature winding by height 1.2 mm.

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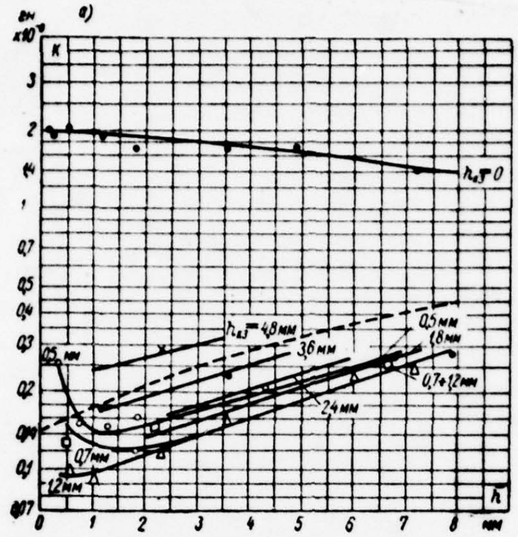


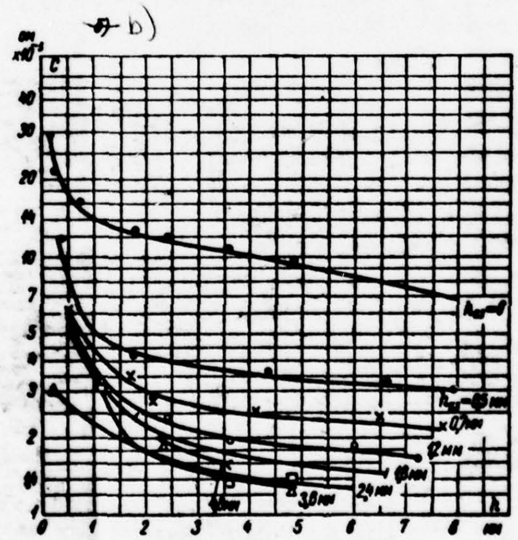


Fig. 8-11. Curved of dependences of coefficients K and C

on height/altitude of test (nonshorted) section of winding of relay of type RKN at frequency 1000 Hz.

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It is interesting to note that the value of coefficient K of last/latter (by heel) armature coil, which has the greatest mean diameter, 3.3 times greater than the value of this coefficient of the first (from core) section.

The average value of coefficient K for an entire winding of relay is approximately 1.5 times greater the value of this coefficient of the first section.

Thus, for obtaining the smallest inductance of relay of the type RKN at frequency 1000 Hz it is necessary to core to place under inducing winding quadrature winding or pure copper tube with thickness (height/altitude) about 1.2 mm (0.133 $d_0$). The diameter of the wire of quadrature winding must be more than 0.1 mm. The height/altitude of working (nonshorted) winding must be as far as possible of small, but it is not less than 0.8-1.0 mm.

The insulation between working and quadrature winding must not have excessive thickness. The obtained here conclusion/derivations, obviously, can be common for any other electromagnetic mechanisms, which have the magnetic system, approximately analogous to the magnetic circuit of relay of the type RKN.

8-6. Examples.

1. Let us determine inductance and effective resistance of relay of type RKN in frequency 1000 Hz, clearance 1.1 mm and variable field approximately in 0.06 A/cm.

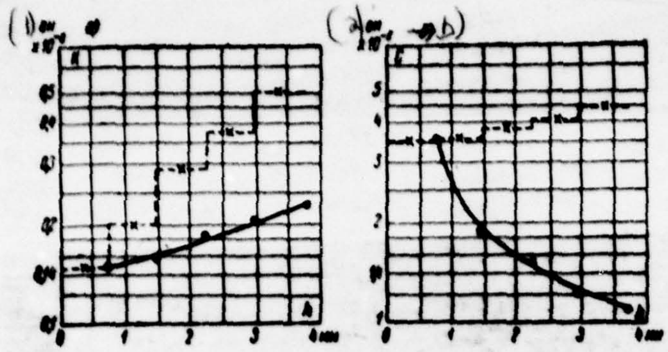

Fig. 8-12. Dependence curves of coefficients K and C against height/altitudes of inducing winding of time-lag relay of type RKN at frequency 1000 HZ ($h_{ш} = 3$ мм).

Key: (1). H. (2). ohm.

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th core, housing and armature are made made of steel of brand E. Number of turns of winding 8000. The voltage of speaking currents on the datum level of transmission about 0.7v; the average strength of field, created by these coil currents of relay, let us accept as the tentatively equal to 0.06 A/cm.

Permeability with H = 0.06 A/cm according to formula (4-1)

$$\mu = \mu_a (1 + 1,25\beta H) = 170 \cdot (1 + 1,25 \cdot 7,7 \cdot 0,06) = 274.$$

The specific conductivity of steel

$$\gamma_1 = \frac{1}{\rho_{ж}} = 0,935 \cdot 10^7 \ сим/м.$$

Key: (1). S/m.

Equivalent thickness of material with frequency 1000 Hz

$$\frac{\Delta}{p_1} = \frac{\sqrt{2}}{\sqrt{\omega \mu \mu_0 \gamma_1}} = \frac{\sqrt{2}}{\sqrt{6280 \cdot 274 \cdot 0,935 \cdot 10^7 \cdot 4\pi \cdot 10^{-7}}} = 3,16 \cdot 10^{-4} \ м.$$

The housing of relay is made made of sheet steel, and core from circular; therefore it is necessary to determine effective permeability separately for core and housing.

For the housing, prepared from sheet steel by thickness 4 mm,

$$p_1 = \frac{4 \cdot 10^{-3}}{3,16 \cdot 10^{-4}} = 12,6.$$

From the curves of Fig. 8-2, we find values of coefficients $A_1$ and $B_1$ for the housing of the relay:

$$A_1 = 0,08 \text{ and } B_1 = 1,0.$$

Effective permeability of the housing of the relay

$$\mu_1 = A_1 \mu = 0,08 \cdot 274 = 21,9.$$

For the core of relay, prepared from round bar steel by diameter 9 mm,

$$p_2 = \frac{d}{2}\sqrt{\omega\mu\mu_0\gamma_1} = \frac{9\cdot 10^{-3}}{2}\sqrt{6280\cdot 274\cdot 0{,}935\cdot 4\pi} = 20{,}2.$$

From the curves of Fig. 8-3, we find values $A_2$ and $B_2$ for the core of the relay:

$$A_2 = 0{,}08 \text{ and } B_2 = 0{,}98.$$

Effective permeability of the core

$$\mu_1' = A_2\mu = 0{,}08\cdot 274 = 21{,}9.$$

Effective reluctance 1 m of the length of the magnetic circuit of the relay

$$R_{\text{м}}' = \frac{1}{\mu_1\mu_0 S_{\text{к}}} + \frac{1}{\mu_1'\mu_0 S_{\text{c}}} = \frac{10^4}{21{,}9\cdot 0{,}82\mu_0} + \frac{10^4}{21{,}9\cdot 0{,}636\mu_0} = \frac{1297}{\mu_0}\ [\text{ав/вб}\cdot\text{м}]^{(1)}.$$

Key: (1). A-t/Wb•m.

Armature has thickness 2 mm, mean section 0.41 cm² and useful length 1.5 cm; consequently, for the armature

$$p_1 = \frac{2\cdot 10^{-3}}{3{,}16\cdot 10^{-4}} = 6{,}33, \qquad A = 0{,}16 \text{ and}$$

$$R_{\text{як}} = \frac{1{,}5\cdot 10^{2}}{0{,}16\cdot 274\cdot 0{,}41\mu_0} = \frac{8{,}3}{\mu_0}\ [\text{ав/вб}]^{(1)}.$$

Key: (1). A-t/Wb.

The reluctance of clearance is equal $4.5/\mu_0$.

Common/general/total reluctance of the clearance of the relay

$$R_в = \frac{4,5}{\mu_0} + \frac{8,3}{\mu_0} = \frac{12,8}{\mu_0} \quad [ав/вб]^{(1)}.$$

Key: (1). A-t/Wb.

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The specific conductivity of leakage fluxes for relay of the type RKN is equal to 3.6.

Value of the coefficient

$$q = \frac{l\sqrt{gR_{мк}}}{\operatorname{th} l\sqrt{gR_{мк}}} = \frac{7 \cdot 10^{-2}\sqrt{3,6 \cdot 1297}}{\operatorname{th} 7 \cdot 10^{-2}\sqrt{3,6 \cdot 1297}} = 4,78.$$

Given effective reluctance of the relay

$$R'_м = \frac{4,78 \cdot 12,8 + 7 \cdot 10^{-2} \cdot 1297}{\left[1 + \frac{12,8}{7 \cdot 10^{-2} \cdot 1297}(4,78 - 1)\right] 4\pi \cdot 10^{-7}} = 7,9 \cdot 10^7 \ [ав/вб]^{(1)}.$$

Key: (1). A-t/Wb.

Value of coefficient K for relay at frequency 1000 Hz

$$K = \frac{1}{R'_м} = \frac{10^{-7}}{7,9} = 1,26 \cdot 10^{-8} \ гн^{(1)}$$

Key: (1). H.

Value of coefficient C at the same frequency

$$C = C_1 + \frac{B_1 + B_2}{2} \omega K = 0{,}375 \cdot 10^{-8} + \frac{1 + 0{,}987}{2} 6280 \cdot 1{,}26 \cdot 10^{-8} = 8{,}23 \cdot 10^{-8} \text{ ом}^{(1)}$$

Key: (1). ohm.

Inductance and the effective resistance of relay at frequency 1000 Hz will be respectively equal to:

$$L = Kw^2 = 1{,}26 \cdot 10^{-8} \cdot 8000^2 = 0{,}81 \text{ гн}^{(1)}$$
$$R = Cw^2 = 8{,}23 \cdot 10^{-8} \cdot 8000^2 = 5270 \text{ ом}^{(2)}$$

Key: (1). Hz. (2). ohm.

2. Let us determine parameters of worker and quadrature windings of relay of type RKN, if inductance of this relay at frequency 1000 Hz must be not more than 0.15 H. the voltage of battery 24 v, the value of circuital current of relay 15 mA. For a reliable work with the assigned load of relay, must have not less than 120 ampere-turns. Turn number of the winding of the relay

$$w = \frac{120}{0{,}015} = 8000.$$

So that the inductance of relay would be less than 0.15 H, the value of coefficient K must be

$$K \leq \frac{L}{w^2} = \frac{0{,}15}{8000^2} = 0{,}234 \cdot 10^{-8} \text{ гн}^{(1)}$$

Key: (1). H.

From the curves of Fig. 8-11, we find that at the height/altitude of quadrature winding 1.2 mm and K = $0.234 \cdot 10^{-8}$ the height/altitude of inducing winding of relay must be not more than 6.1 mm, but coefficient C will be equal to $1.8 \cdot 10^{-5}$ to ohm.

The diameter of wire and direct-current resistance of inducing winding with h = 6.1 mm and w = 8000 will be respectively equal: d = 0.19 mm (PEL) and r = 262 ohm.

Inductance, the active and impedance of relay at frequency 1000 Hz will be:

$$L = 0{,}15\ \text{гн}^{(1)},\ R = 1{,}8 \cdot 10^{-5} \cdot 8000^2 = 1150\ \text{ом}^{(2)}\ \text{и}\ Z = 1486\ \text{ом}.^{(2)}$$

Key: (1). H. (2). ohm.

If the height/altitude of inducing winding is accepted equal to 1 mm, then the wire diameter will be equal to 0.06 mm (PEL), but direct-current resistance will increase more than 6 times and will be equal to 1610 ohm.

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The inductance of relay in this case will be approximate 2.5 times less, but **impedance** is 2 **times** more, namely:

$$L = 0{,}096 \cdot 10^{-6} \cdot 8000^2 = 0{,}0615 \text{ гн}^{(1)}$$

Key: (1). the H

and

$$R = 3{,}87 \cdot 10^{-6} \cdot 8000^2 = 2480 \text{ ом}^{(1)}.$$

Key: (1). ohm.

But a voltage drop across the winding of relay in this case will be too greatly: U = 0.015•1610 = 24.2 V.

In the absence of quadrature winding, the inductance and the effective resistance of this relay would be respectively equal to:

$$L = 1{,}24 \text{ гн and } R = 8950 \text{ ом}^{(1)}.$$

Key: (1). ohm.

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Chapter Nine.

# HEATING THE WINDINGS OF RELAYS.

## 9.1. Heating with a constant value of power input.

The thermal field of the winding of relay is three-dimensional, and its structure is heterogeneous. However, within the winding of the relays, with the exception of places, located in immediate proximity to bounding surfaces, the gradient of temperature is small, and temperature in the height/altitude of winding differs little from average.

Therefore for the engineering calculations by the gradient of temperature within the winding of relay, it is possible to disregard and to consider heat flux through bounding surfaces proportional to the difference between mean temperature of winding and the ambient temperature.

the heat removal from the winding of relay by natural or forced cooling is realized by three fundamental methods of the heat transfer: by thermal conductivity, convection and emission/radiation. Heat emission by means of thermal conductivity is proportional to temperature excess in the first degree (fourier law), heat transfer because of convection during natural cooling is proportional to the temperature of reheating in degree of approximately 1.25, while heat emission caused by emission/radiation is proportional to a difference in the fourth degrees of the absolute temperatures of the surface of the radiating body and surrounding air (law of Stephan-Boltzmann).

Consequently, overall heat emission by hot body is complex function of its temperature.

However, the overheating of the windings of relay usually has comparatively small value: therefore for tentative engineering calculations it is possible to be restricted to one average heat-transfer coefficient q, counting the value of its constant during small changes temperature of winding.

Let us examine the mode of heating the winding of relay. For simplicity let us assume that the winding is ideal uniform solid body, which is heated completed evenly and temperature of which in all points is identical.

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Then for heating of winding it is possible to write the following equation:

$$P\,dt = S_{ox}\, q\vartheta\, dt + Qc\, d\vartheta, \qquad (9\text{-}1)$$

where P - the power in W, which is isolated in winding, 1 s, $S_{ox}$ - the cooling surface of coil in cm², q - heat-transfer coefficient (specific heat emission) in W/cm²•deg; $\vartheta$ - temperature excess of the winding above the ambient temperature in °C - Q- the weight of winding in g and s - specific heat in J/g•deg.

If power input is constant, then the temperature of body gradually is raised, dissipation of heat increases, and the excess of heat, which goes to an increase in the temperature, decreases. Through certain time the excess of heat will make equal to zero, and the temperature of

winding will be achieved the steady value.

In this case $d\vartheta$, is equal to zero and

$$P = S_{ox}\, q\vartheta_{y}, \tag{9-2}$$

where $\vartheta_y$ - established temperature excess.

From last/latter equation we obtain formula for steady temperature excess of uniform body (Newton's formula):

$$\vartheta_y = \frac{P}{qS_{ox}}. \tag{9-3}$$

Virtually the winding of relay is heterogeneous body; furthermore, cooling conditions of the external and internal surfaces of coil are different. The external cylindrical surface of coil freely washes by the ascending air and it is cooled well, and internal (cylindrical or rectangular) surface gives up heat to the steel core of the relay through the layer of insulation (coil form), which separate/liberates winding from core.

The heat removal on the internal surface of coil depends on thickness and thermal conductivity of the layer of insulation (or framework/body), the value of air gaps between the winding and the core and of thermal

conductivity of the magnetic circuit of relay. Because of this the temperature in the different layers of winding is different.

Faces of coil are usually small in comparison with its external (cylindrical) surface; furthermore, they are largely closed by thick jaws out of getinax (or plastic). Therefore the heat removal through faces can be disregarded.

However, when the diameter of coil is greater than its length, the cooling surfaces of jaws must be considered.

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Average steady temperature excess of the winding of the relay of the direct current above the ambient temperature at steady-state thermal condition can be expressed by following formula [1. 9-5]:

$$\vartheta_y = \frac{P}{\varphi(S_н + aS_в)},$$

where $S_H$ - the external cooling surface of coil in cm², $S_B$ - the internal cooling surface of coil in cm² and a - the coefficient, depending on the value of the heat emission through the core of relay.

The experimental investigations, carried out on relay of the type RKN, showed that the value of coefficient a of these relay usually varies within limits from 0.9 to 1.3. Of the relay of large overall size with the frame-less compounded winding from heavy-gauge wire, coefficient a reaches to 2.4.

The value of the internal cooling surface of coil usually is considerably lower than external; therefore a change in coefficient of a comparatively little affects the final result of calculation.

For the practical engineering calculations of heating the electromagnetic relays of direct current, the calculated value of the cooling surface of coil is usually accepted equal to the sum of the external and internal cooling surfaces of the coil of relay.

In this case for the average value of steady temperature excess (overheating of the winding of relay we obtain:

$$\vartheta_y = \frac{P}{q_1 (S_н + S_в)} = \frac{P}{q_1 S_н}, \qquad (9\text{-}4)$$

where $q_1$ mean (conditional) heat-transfer coefficient of the coil of relay, determined experimentally, and $S_K$ - the calculated cooling surface of coil.

Below, in § 9-7, it is shown, that the value of average heat-transfer coefficient depends on the temperature of winding (9-46):

$$q_1 = q_0 + e\Theta = q_0 + e(\Theta_0 + \vartheta_y),$$

where $q_0$ is an average heat-transfer coefficient of winding with temperature of 0°C, e - tangent of the slope/inclination of the curve of dependence $q_1$ on the temperature of winding, $\Theta_0$ - an ambient temperature and $\Theta$ - mean temperature of the winding of relay.

Substituting in equation (9-4) instead of $q_1$ its value of the given below formula (9-46), we obtain more exact expression for average excess of the temperature of the winding of the relay:

$$\vartheta_y = \frac{P}{S_K[q_0 + e(\Theta_0 + \vartheta_y)]},$$

whence

$$\vartheta_y = \sqrt{\left(\frac{q_0 + e\Theta_0}{2e}\right)^2 + \frac{P}{eS_K}} - \frac{q_0 + e\Theta_0}{2e}. \qquad (9\text{-}5)$$

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The investigations, carried out by author, showed that if was known the temperature of the overheating of the winding of relay $\vartheta_{y1}$ at the temperature of surrounding air $\Theta_{01}$, then the temperature of the overheating of the winding of this relay with the same power and different ambient temperature $\Theta_{02}$ can be determined by the following approximation formula [1. 1-15]:

$$\vartheta_{y_2} \approx \vartheta_{y_1}[1-(1{,}91+0{,}0036\cdot\Theta_{01})\cdot 10^{-3}(\Theta_{02}-\Theta_{01})]. \quad (9\text{-}6)$$

If the initial ambient temperature $\Theta_{01} = 20°C$, then

$$\vartheta_{y2} \approx \vartheta_{y1}[1-0{,}00198(\Theta_{02}-20)]. \quad (9\text{-}6a)$$

Hence it follows that with the same amount of power in winding with an increase in the temperature of surrounding air by 10°C (within limits from 0 to 100°C) overheating of the windings of electromagnetic miniature/small relays (without jackets) it decreases approximately by 2o/o.

Establish/installed conditions/mode.

For obtaining the dependence of temperature excess of the winding of relay (ideal solid body) from time let us substitute into equation (9-1) instead of P its value from expression (9-2): we will obtain:

$$(\vartheta_y-\vartheta)S_{ox}q\,dt=Qc\,d\vartheta \quad \text{(1)} \quad dt=\tau\frac{d\vartheta}{\vartheta_y-\vartheta},$$

Key: (1). or

where $\tau=\frac{Qc}{S_{ox}q}$ - time constant of heating.

In this case, value q let us consider not depending on temperature. Integrating last/latter equation, we obtain:

$$t=\tau\int\frac{d\vartheta}{\vartheta_y-\vartheta}=\tau[-\ln(\vartheta_y-\vartheta)+c_1].$$

Integration constant we find from initial conditions. With t = 0, we set/assume $\vartheta=\vartheta_0$: then $c_1=\ln(\vartheta_y-\vartheta_0)$.

Substituting in equation for t instead of $C_1$ its value, we find:

$$t=\tau[-\ln(\vartheta_y-\vartheta)+\ln(\vartheta_y-\vartheta_0)]=-\tau\ln\frac{\vartheta_y-\vartheta}{\vartheta_y-\vartheta_0}.$$

From this equation we obtain:

$$\frac{\vartheta_y-\vartheta}{\vartheta_y-\vartheta_0}=e^{-\frac{t}{\tau}}.$$

whence

$$\vartheta = \vartheta_y - (\vartheta_y - \vartheta_0)e^{-\frac{t}{\tau}} \text{ или } \vartheta = \vartheta_y(1 - e^{-\frac{t}{\tau}}) + \vartheta_0 e^{-\frac{t}{\tau}}. \quad (9\text{-}7)$$

Key: (1). or.

If in the beginning of the conditions/mode of heating the temperature of winding is equal to ambient temperature, then $\vartheta_0 = 0$ and formula (9-7) are simplified:

$$\vartheta = \vartheta_y(1 - e^{-\frac{t}{\tau}}). \quad (9\text{-}7a)$$

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ab The equation of cooling the coils of relay after the disconnection of current can be obtained from the equation of heating, if we place from some moment of time inflow of heat equal to zero:

$$S_{ox}'q\vartheta\, dt + Qc\, d\vartheta = 0 \text{ или } \frac{d\vartheta}{\vartheta} = -\frac{dt}{\tau}.$$

Key: (1). or.

Integrating the last equation, we obtain $\ln \vartheta = -t/\tau + c$.

With $t = 0$, we have $\vartheta = \vartheta_a$; consequently, $c = \ln \vartheta_a$. Substituting the value of c, we will obtain:

$$\ln \frac{\vartheta}{\vartheta_a} = -\frac{t}{\tau},$$

whence we find:

$$\vartheta = \vartheta_a e^{-\frac{t}{\tau}}. \qquad (9\text{-}8)$$

The time constant of heating the winding of relay depends on the heating time, since relay is heterogeneous body, which consists of different materials (copper, enamel, paper, varnished cambric, steel, etc.) with different specific heat and different thermal conductivity.

Furthermore, in the process of heating the winding of relay heat partially is transmitted steel of the magnetic circuit through the layer of insulation and air, which separate/liberates core from winding. Therefore the precision determination of the time constant of heating the winding of relay is very complex problem.

For practical calculations it is possible to use the simplified approximation formula [1. 4-19, 4-22]:

$$\tau = \frac{Q_M c_M + bQ_c c_c}{q_1 S_n}. \qquad (9\text{-}9)$$

where $Q_M c_M$ is heat capacity of copper and insulation of

winding, $Q_c c_c$ - heat capacity they will stop magnetic circuit and b - the coefficient, considering the heat transfer from winding to steel.

The value of coefficient b depends also on the time of heating and value

$$n = \frac{Q_c c_c}{S_\kappa}. \qquad (9\text{-}10)$$

With the time of heating t > τ/3 and to good heat transfer from winding to core (frame-less windings) value $b_\kappa = 0{,}55$, at poor heat transfer $b_n = 0{,}45$.

With the time of heating t < τ/3 and n = 1.25; $b_\kappa = 0{,}55$ and $b_n = 0{,}45$; with n > 5: $b_\kappa = 0{,}275$ and $b_n = 0{,}225$.

With t < τ/3 and 1.25 < n < 5: $b_\kappa = 0{,}55\left(0{,}5 + 0{,}5\,\frac{5-n}{3{,}75}\right)$ and $b_n = 0{,}45\,\left(0{,}5 + 0{,}5\,\frac{5-n}{3{,}75}\right)$.

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It is necessary to also consider that the constant value of the time of heating winding depends on the mode of the work of relay with direct current or with

direct/constant voltage. Therefore the more precise value of the time constant of heating can be found experimentally on growth curve of the temperature of the overheating of the winding of relay.

Figures 9-1 gives the curves of the dependences of average temperature excess of the winding of relay of the type RKN from time at a constant value of the applied voltage U and of a constant value of current I in winding, and also the cooling curve of the winding of the relays, obtained experimentally [1. 9-17]. By dotted line are shown exponential curves.

From Fig. 9-1 it follows that the deviation of heating curves of the winding of relay from the exponential is comparatively small. The curve of temperature excess of the winding of relay grows first faster, but through t = τ is slower than exponent.

With a constant value of the applied voltage (curved 1) the time constant heating is less than with a constant value of coil current (curved 2) approximately 1.5 times.

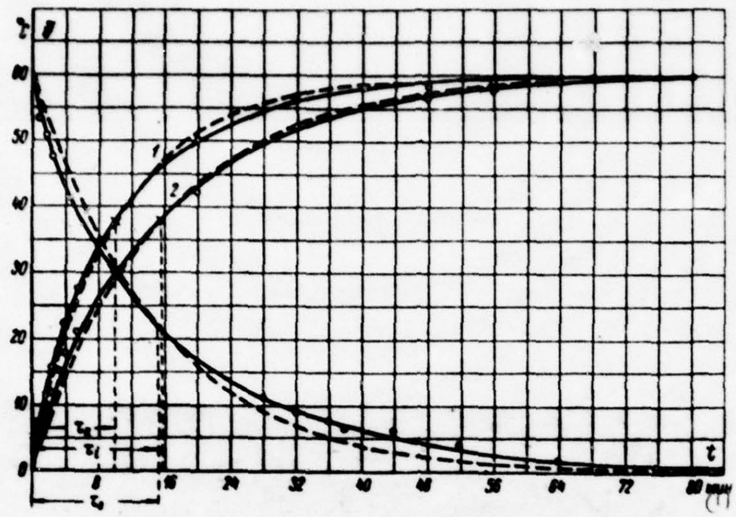


Fig. 9-1. Dependence curves of average temperature excess of winding of relay of type RKN from time. 1 = U = const; 2 = I = const.

Key: (1). min.

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The time constant of cooling the coils of relay is virtually equal to time constant of heating winding with I = const, $\vartheta$ = 60°C and $\theta_0$ = 20°°C. In a similar manner

were obtained approximate values of the time constant of heating for the relay of different value and weight, referring of the length of core to its diameter approximately from 3 to 8.

With the aid of these data in Fig. 9-2 are constructed the curves of the dependences of the time constant of heating the windings of valve type relay on weight of relay with U = const (curved 1), I = of const (curved 2) and P = const (curved 3). These dependences in logarithmic scale are expressed by straight lines and can be determined by the following approximation formulas:

$$\left.\begin{aligned} \tau &\approx (0{,}77 \div 1{,}07)\sqrt{Q} \text{ при}^{(1)}\ P = \text{const}, \\ \tau_u &\approx (0{,}6 \div 0{,}9)\sqrt{Q} \text{ при } U = \text{const}, \\ \tau_i &\approx (1{,}0 \div 1{,}4)\sqrt{Q} \text{ при } I = \text{const}, \end{aligned}\right\} \quad (9\text{-}11)$$

Key: (1). with.

where $\tau$ is time constant of heating relay in minutes and $Q$ - the weight of relay in grams.

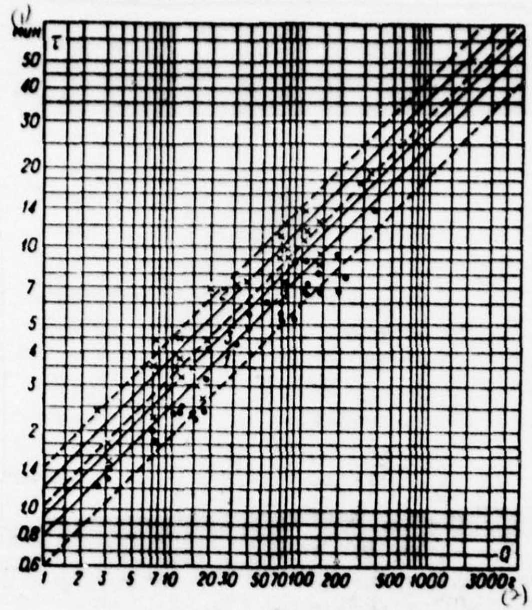


Fig. 9-2. Tentative curves of dependences of time constant of heating winding on weight of relay with $\vartheta$ = 60°C and $\theta_0$ = 20°C. 1 - U = const; 2 - I = const; 3 - P = const.

Key: (1). min. (2). g.

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Solving together equations (9-53a) and (9-54a) relative to Q and substituting its value in expressions (9-11), we

obtain the approximation formulas for the time constant of heating depending on the cooling surface of the winding of the relay:

$$\tau \approx 1{,}15 \sqrt[4]{S_{\text{к}}^{3}};\ \tau_{\text{и}} \approx 0{,}94 \sqrt[4]{S_{\text{к}}^{3}};\ \tau_{l} \approx 1{,}25 \sqrt[4]{S_{\text{к}}^{3}}. \qquad (9\text{-}12)$$

9-2. Heating with a constant value of the conducted/supplied voltage.

The dependence of the resistor/resistance of wire on temperature, as is known, is expressed by the following formula:

$$R = R_0 [1 + \alpha (\Theta - \Theta_0)] = R_0 (1 + \alpha \vartheta), \qquad (9\text{-}13)$$

where $R_0$ - winding impedance at initial temperature $\Theta_0$ and $\alpha$ - temperature specific resistance of copper wire whose value within limits from -200 to +300°C is equal to

$$\alpha = \frac{1}{234{,}5 + \Theta_0}. \qquad (9\text{-}14)$$

This dependence they frequently use for determining average temperature excess of the heated winding. From equation (9-13) we find formula for determining average temperature excess of the winding:

$$\vartheta = \frac{R - R_0}{R_0} (234{,}5 + \Theta_0) + \Theta_0 - \Theta_a. \qquad (9\text{-}15)$$

where $\Theta_a$ - the ambient temperature at the end of the heating.

In local circuit the winding of relay is included to assigned direct/constant voltage of battery; in this case the coil losses of relay do not remain constants, but are gradually decreased with an increase in temperature excess:

$$P = \frac{U^2}{R} = \frac{U^2}{R_0\left(1 + \frac{\vartheta_{y1}}{234{,}5 + \Theta_{01}}\right)} = \frac{P_н}{1 + \frac{\Theta - \Theta_{01}}{234{,}5 + \Theta_{01}}}, \quad (9\text{-}16)$$

where $R_0$ - winding impedance, measured at the temperature of surrounding air $\Theta_{01}$, usually equal about 20°C, $P_н$ - the initial power, consumed by the unheated winding of relay at the moment of its connection/inclusion at the ambient temperature $\Theta_{01}$ and $\vartheta_{y1}$ - temperature excess of the winding above the temperature $\Theta_{01}$.

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If relay is located at another ambient temperature $\Theta_{02}$, then $\Theta = \Theta_{02} + \vartheta_{02}$, and the required power will be equal to:

$$P = \frac{P_н}{1 + \frac{\Theta_{02} + \vartheta_{y2} - \Theta_{01}}{234{,}5 + \Theta_{01}}} = \frac{P_н\,(234{,}5 + \Theta_{01})}{234{,}5 + \Theta_{02} + \vartheta_{y2}}, \quad (9\text{-}16a)$$

where $\vartheta_{y2}$ is an excess of mean temperature of the winding

above the ambient temperature $\theta_{02}$.

Let us substitute into equation (9-4) instead of values p and $q_0$ of their value from (9-16a) and (9-46); we obtain:

$$\vartheta_{y2}=\frac{\frac{P_{н}(234{,}5+\Theta_{01})}{234{,}5+\Theta_{02}+\vartheta_{y2}}}{[q_0+e(\Theta_{02}+\vartheta_{y2})]S_{к}}=\frac{P_{н}(234{,}5+\Theta_{01})}{S_{к}[q_0+e(\Theta_{02}+\vartheta_{y2})](234{,}5+\Theta_{02}+\vartheta_{y2})}$$

or

$$\vartheta_{y2}S_{к}[q_0+e(\Theta_{02}+\vartheta_{y2})](234{,}5+\Theta_{02}+\vartheta_{y2})-P_{н}(234{,}5+\Theta_{01})=0.$$

After conversions we obtain the expression, which is the equation of cube relatively $\vartheta_{y2}$:

$$\vartheta_{y2}^2[q_0+e(234{,}5+2\Theta_{02}+\vartheta_{y2})]+\vartheta_{y2}(q_0+e\Theta_{02})(234{,}5+\Theta_{02})-\frac{P_{н}}{S_{к}}(234{,}5+\Theta_{01})=0.$$

For simplification let us introduce the following designations:

$$A_1=q_0+e(234{,}5+2\Theta_{02}+\vartheta_{y2});\quad B_1=(q_0+e\Theta_{02})(234{,}5+\Theta_{02}) \text{ and } C_1=\frac{P_{н}}{S_{к}}(234{,}5+\Theta_{01});$$

Then

$$A_1\vartheta_{y2}^2+B_1\vartheta_{y2}-C_1=0.$$

Value $\vartheta_{y2}$ usually is within the limits from 20 to 80°C and it is small in comparison with sum (234.5 + $2\theta_{02}$). Therefore it is possible sufficient for practical calculations by accuracy to accept value $A_1$ equal to:

$$A_1\approx q_0+e(234{,}5+2\Theta_{02}+50)\approx q_0+e(285+2\Theta_{02}).$$

Solving quadratic equation, we obtain the approximation formula for determining the mean value of the excess of temperature of the winding above the temperature of surrounding air at the constant value of the applied voltage:

$$\vartheta_{y_2} \approx \frac{\sqrt{B_1^2 + 4A_1C_1} - B_1}{2A_1}. \qquad (9\text{-}17)$$

If during calculation value $\vartheta_{y_2}$ proves to be much more than 50°C, then value $A_1$ can be refined and repeated calculation at the new value $A_1$.

Thus, by successive repeating it is possible to determine value $\vartheta_{y_2}$ with sufficient accuracy.

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If we accept the value of the average heat-transfer coefficient $q_1$ of constant, that virtually it is possible to allow only at the small temperatures of overheating and during small changes in the ambient temperature, then for the temperature of the overheating of the winding of relay at the ambient temperature $\theta_{02}$ we will obtain the following

expression ] 1. 1-15]:

$$\vartheta_{ym} = \frac{234{,}5 + \Theta_{02}}{2}\left[\sqrt{1 + \frac{4\vartheta_1 P_n (234{,}5 + \Theta_{01})}{234{,}5 + \Theta_{02}}} - 1\right]. \quad (9\text{-}18)$$

where

$$\vartheta_{oy} = \vartheta_1 P_n.$$

In these formulas $\vartheta_{oy}$ - steady temperature excess, which has the winding of relay at the ambient temperature $\Theta_{01}$, if the initial required power $P_n$ does not change and $\vartheta_1$ - temperature excess of the winding of this relay on 1 W (specific temperature excess).

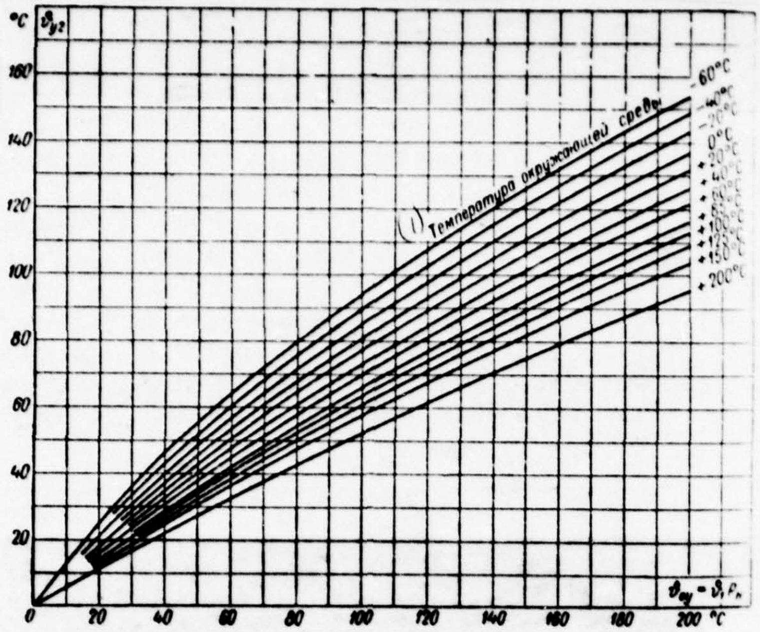


Fig. 9-3. Dependence curves of steady temperature excess of the winding of the relay above the temperature of surrounding air from value $\vartheta_1 P_н$ at U = const.

Key: (1). Ambient temperature.

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Figures 9-3 gives dependence curves of steady

temperature excess of the winding of the relay above the temperature of surrounding air $\theta_{02}$ at constant value of the conducted/supplied voltage from temperature excess $\vartheta_{0y}$ and $\theta_{01}$ = 20°C, constructed by author with the aid of formula (9-18).

At a constant value of the applied voltage, the temperature of winding grows first faster than with constant losses. The time constant of heating with direct/constant voltage is equal [1. 1-15]:

$$\tau_u = \frac{2\tau}{1+\sqrt{1+4\alpha\vartheta_{0y}}}. \qquad (9\text{-}19)$$

the initial section of heating curve virtually coincides with exponential; however, subsequently with an increase in the temperature of the winding of the loss gradually are decreased and the velocity of the increase of temperature considerably slows down. Therefore for achievement of final conservative value of temperature, is required approximately 5 times of more time, than in the case damping constant in winding.

Simplified formulas for the calculation of the temperature of overheating of the windings of relay.

The determination of the temperature of the overheating of the windings of relay with the aid of formula (9-17) requires comparatively much time.

Within the limits of a change in the temperature of the overheating of the windings of relay approximately from 35 to 90°C can be obtained considerably simpler and more convenient approximation formulas.

Figures 9-4 gives average dependence curves of steady temperature of overheating of the winding of the relay of types RES8, RES9, RES10 and RES15 from the value of the applied voltage at the temperature of surrounding air of approximately 20°C and normal atmospheric pressure. These curves within the limits of most frequently encountered values of the temperature of the overheating of windings approximately from 35 to 90°C do not in practice differ from straight lines.

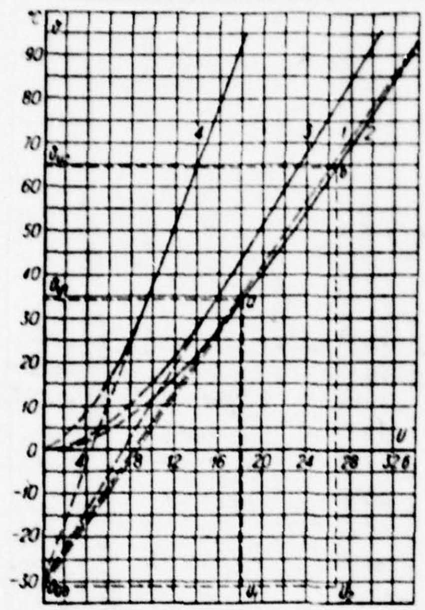


Fig. 9-4. dependence curves of the temperature of the overheating of relay from the applied voltage at $\theta_0$ = 20°C. 1 - relay of the type RES8; 2 - relay of the type RES9; 3 - relay of the type RES10; 4 - relay of the type RES15.

End section.

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If we continue these straight lines by dotted line down before intersection with the axis of ordinates, then it is easy to ascertain that the direct/straight for all four types relays transverse axis ordinate at points $\vartheta_{u0}$, which are located not far from each other.

We will take on any temperature slope of overheating within limits from 35 to 90°C two points a and b let us drop from these points perpendiculars on the axis of coordinates.

From the similarity of triangles $\vartheta_{y1}a\vartheta_{u0}$ and $\vartheta_{y2}b\vartheta_{u0}$ we find

$$\frac{\vartheta_{y1}+\vartheta_{u0}}{U_1}=\frac{\vartheta_{y2}+\vartheta_{u0}}{U_2} \text{ or } \vartheta_{y1}+\vartheta_{u0}=\frac{U_1}{U_2}(\vartheta_{y2}+\vartheta_{u0}),$$

whence

$$\vartheta_{y1}=\frac{U_1}{U_2}(\vartheta_{y2}+\vartheta_{u0})-\vartheta_{u0}. \qquad (9\text{-}20)$$

Let us multiply numerator and the denominator of the right side of equation (9-20) on $\sqrt{R_0}$, we will obtain:

$$\vartheta_{y1} = \frac{U_1 \sqrt{R_0}}{U_2 \sqrt{R_0}} (\vartheta_{y2} + \vartheta_{u0}) - \vartheta_{u0}, \qquad (9\text{-}20a)$$

where $R_0$ - the resistor/resistance of unheated winding at temperature of 20°C (initial winding impedance).

Let us designate:

$$a = \frac{\sqrt{R_0}}{U_2} (\vartheta_{y2} + \vartheta_{u0}). \qquad (9\text{-}21)$$

Then for determining mean temperature of the overheating of winding within limits from 35 to 90°C at the constant value of load voltage of relay we obtain from equation (9-20a) the very simple formula:

$$\vartheta_{y1} = a \frac{U_1}{\sqrt{R_0}} - \vartheta_{u0} = a \sqrt{P_{m1}} - \vartheta_{u0}, \qquad (9\text{-}22)$$

where $P_{m1}$ — the initial power, consumed by unheated winding at voltage $U_1$ and temperature +20°C (at the moment of the connection/inclusion of winding $P_{m1} = U_1^2/R_0$); - the coefficient, which characterizes construction and the size/dimensions of relay and $\vartheta_{u0}$ — the point of intersection of the continuation of the straight line of overheating with the negative section of axis of ordinate.

The value of coefficient of a for any type of relay can be found experimentally.

For determining value $\vartheta_{u0}$ it is necessary to measure the temperature of the overheating of winding within limits from 35 to 90°C at two different values of voltage.

In this case from equation (9-20) we obtain for $\vartheta_{u0}$ the following expression:

$$\vartheta_{u0} = \frac{\vartheta_{y2} U_1 - \vartheta_{y1} U_2}{U_2 - U_1}. \quad (9\text{-}23)$$

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Investigations showed that $\vartheta_{u0}$ for the different types of miniature/small relays at ambient temperature of 20°C oscillates within limits approximately from 23.1 to 33.6°C. The average value of quantity $\vartheta_{u0}$ is equal to 28.5°C. The deviations of value $\vartheta_{u0}$ of different types of relay from average value are +5.1 and -5.4°C (+18 and -19ɔ/ɔ). At atmospheric pressure 50 mm Hg temperatures 20°C value of quantity $\bar{\vartheta}_{u0}$ for the different types of relay varies within limits approximately from 26.7 to 37°C. Average value $\vartheta_{u0}$ is equal to 31°C.

In Fig. 9-5 are constructed dependence curves of steady temperature of the overheating of the windings of the different types of relay under normal conditions at constant load voltage of relay from the initial power, consumed by unheated winding at temperature of 20°C.

The scale of grid along the axis of abscissas is proportional to square root of initial power. On this scale grid these curves within the limits of changes in the temperature of the overheating of windings from 35 to 90°C do not in practice differ from straight lines. The value of coefficient a is equal to the slope tangent of these direct/straight to axis ordinates:

$$a=\frac{\vartheta_y+\vartheta_{u0}}{\sqrt{P_H}}. \quad (9\text{-}21a)$$

Table 9-1 gives average values of coefficients of a and $\vartheta_{u0}$ for the different types of relay at ambient temperature 20°C and two values of the atmospheric pressure: 760 and 50 mm Hg, obtained experimentally. On by the datum of Table 9-1 and Fig. 9-6 are constructed the curved 1 and 2 dependences of values a and $a_1$ (led to values, with respect equal to 28.5 and 31°C) from the size/dimensions of cooling surface of the winding of relay at different atmospheric pressures.

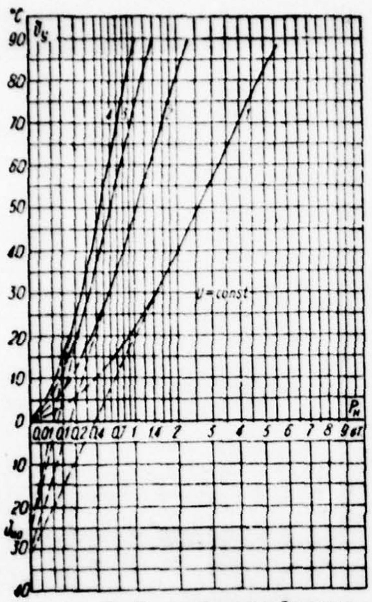


Fig. 9-5. Dependence curves of temperature of overheating of windings of relay from initial power at constant value of voltage and $\theta_0 = 20°C$: 1 - relay of the type RES8; 2 - relay of the type RES9; 3 - relay of the type RES10; 4 - relay of the type RES15.

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Table 9-1. Average values of coefficients $a$, $\vartheta_{н0}$, $b$ and $\vartheta_{10}$

| (1) Атмосферное давление | | 760 мм рт. ст. (2) | | | | | | 50 мм рт. ст. (2) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (3) Тип | $S_к$, см² | $a$ | $\vartheta_{н0}$ °C | $\vartheta_{н0}=28,5$ °C $a'$ | $b$ | $\vartheta_{10}$ °C | $\vartheta_{10}=57$ °C $b'$ | $a_1$ | $\vartheta_{н0}$ °C | $\vartheta_{н0}=31$ °C $a'_1$ | $b_1$ | $\vartheta_{10}$ °C | $\vartheta_{10}=62$ °C $b'_1$ |
| РЭС6 | 10,2 | 67,0 | 26,8 | 68,6 | 113,6 | 57,0 | 113,6 | 81,8 | 26,7 | 86,5 | 133,5 | 53,2 | 144,5 |
| РЭС7 | 22,5 | 48,4 | 29,5 | 47,9 | 81,5 | 59,4 | 79,6 | | | | | | |
| РЭС8 | 18,0 | 46,5 | 25,5 | 48,5 | 89,0 | 67,0 | 81,4 | 59 | 31,1 | 59 | 96,5 | 59,1 | 99 |
| РЭС9 | 7,6 | 80,0 | 31,0 | 77,6 | 125 | 55,7 | 126,5 | 97,2 | 31,9 | 96,3 | 158,5 | 63,9 | 156 |
| РЭС10 | 3,2 | 99,0 | 26,4 | 102 | 168 | 59 | 165 | 134 | 37 | 125 | 219 | 65,7 | 212 |
| РЭС15 | 2,4 | 116 | 26,5 | 119 | 203 | 60,9 | 196 | 149 | 31,5 | 148 | 255 | 62,0 | 255 |
| РЭС22 | 9,6 | 73,1 | 29,7 | 72,2 | 119,6 | 57,9 | 118,7 | 84 | 28,3 | 87 | 149 | 68,7 | 140 |
| РМУ | 22,6 | 48,5 | 28,5 | 48,5 | 81 | 57,0 | 81 | 64,7 | 31,6 | 64,3 | 102,5 | 56,5 | 107,5 |
| РМУГ | 22,6 | 51,0 | 26,5 | 52,4 | 82,3 | 49,6 | 88,5 | 65 | 36,0 | 61,1 | 97,3 | 58,6 | 100,2 |
| РС-13 | 25,0 | 50 | 27,5 | 50,7 | 84,7 | 59,1 | 83,2 | 68,3 | 34,8 | 65,4 | 110 | 62,3 | 110 |
| РСЧ-52 | 27,5 | 54,3 | 30,6 | 53 | 72 | 46,5 | 80 | 70 | 37 | 65,1 | 109 | 61,3 | 108,7 |
| РКМП | 46,9 | 34,9 | 23,6 | 37,2 | 59,7 | 55,6 | 60,4 | 46,5 | 29,4 | 47,4 | 82,6 | 67,2 | 78,8 |
| РКМ-1 | 34,9 | 42,3 | 23,1 | 45,4 | 67,8 | 46,9 | 75 | 52,4 | 28,9 | 54 | 86,8 | 56,7 | 91 |
| РКН | 60,2 | 33,2 | 25,8 | 34,5 | 53,3 | 50,7 | 56,6 | | | 42,4 | | | 71,4 |
| РПН | 50,9 | 34,2 | 21,6 | 37,6 | 57,0 | 48,9 | 61,7 | — | — | 45,6 | — | — | 76 |
| РЭС14 | 48,1 | 38,6 | 28 | 38,9 | 56 | 43,0 | 64,5 | — | — | 48,1 | — | — | 80 |
| ТКЕ21ПД | 8,7 | 73,6 | 29 | 73 | 124 | 64,5 | 116 | — | — | 81 | — | — | 136 |
| ТКЕ52ПД | 15,0 | 55,9 | 29,2 | 55,4 | 99,3 | 65,4 | 92 | | | 60 | | | 101 |
| ТКД12ПД | 26,0 | 46,4 | 29,7 | 45,8 | 81 | 61,4 | 77,8 | — | — | 50 | — | — | 84 |
| КДР1 | 90,4 | 27,9 | 24 | 29,6 | 50,3 | 59,4 | 49,1 | | | | | | |

Key: (1). Atmospheric pressure. (2) mm Hg. (3). Type.

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These dependences on logarithmic scale within limits from 2 to 60 cm² are virtually straight lines, which can be approximated by following approximate formula:

$$a \approx a_0 S_к^{-c}, \qquad (9\text{-}24)$$

where $a_0$ and c are constant coefficients.

The value of coefficient $a_0$ is equal to value of a with the cooling surface in 1 $cm^2$, and coefficient c is equal to the slope tangent of straight line to the axis of abscissas.

From the curves of Fig. 9-6, we find: at the normal atmospheric pressure $a_0$ = 164 and c = 0.38, and at the pressure 50 mm Hg $a'_0$ = 205 and c' = 0.38.

consequently, at normal atmospheric pressure and ambient temperature 20°C

$$a \approx 164 S_{\text{н}}^{-0,38}. \qquad \text{(9-24a)}$$

Substituting in equation (9-22) instead of a and $\vartheta_{\text{м0}}$ their values, we obtain for determining mean temperature of the overheating of winding at the constant value of load voltage of relay under normal conditions (ambient temperature 20°C) the following approximation formula:

$$\vartheta_{\text{у}} \approx \frac{164U}{S_{\text{н}}^{0,38}\sqrt{R_0}} - 28,5 = 164\, S_{\text{н}}^{-0,38}\sqrt{P_{\text{н}}} - 28,5. \qquad \text{(9-25)}$$

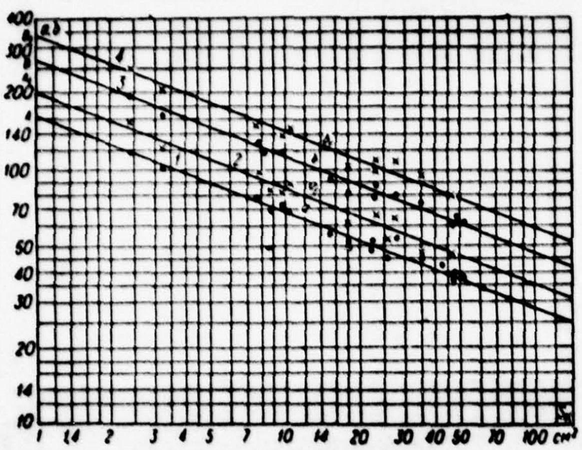


**Fig. 9-6. Dependence curves** of corrected values of coefficients of a, $a_1$, b and $b_1$ from value of calculated cooling surface of winding. 1 - atmospheric pressure p = 760 mm Hg; 2 - P = 50 mm Hg, 3 - P = 760 mm Hg; 4 - P = 50 mm Hg.

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This formula is used within the limits of a change in the temperature of the overheating of the winding of relay approximately from 35 to 90°C under normal conditions (temperature of ambient air 20°C).

At atmospheric pressure 50 mm Hg and temperature 20°C temperature of the overheating of winding at constant load voltage of relay will be equal to:

$$\vartheta_y \approx \frac{205U}{S_{\text{н}}^{0,38}\sqrt{R_0}} - 31 = 205\, S_{\text{н}}^{-0,38}\sqrt{P_{\text{н}}} - 31. \qquad (9\text{-}25a)$$

Error during the determination of the temperature of the overheating of the windings of relay with the aid of formula (9.25), in spite of the considerable deviations of value $\vartheta_{u0}$ from average value, does not exceed +5o/o. At the temperatures of the overheating of winding, it is less than 35°C and more than 90°C error in the calculation increases.

The obtained above formulas can be also used for determining the tentative value of the temperature of the overheating of the winding of relay at other temperatures of surrounding air $\Theta_{02}$, if we instead of $R_0$ substitute the initial resistor/resistance of this winding $R_{02}$ at the temperature $\Theta_{02}$, calculated with the aid of (9-13).

9.3. Heating with a constant value of coil current of relay.

With a constant value of coil current of the relay

$$P = I^2R = I^2R_0\left(1 + \frac{\Theta_{02} + \vartheta_{y2} - \Theta_{01}}{234,5 + \Theta_{01}}\right) = P_{\text{н}}\,\frac{234,5 + \Theta_{02} + \vartheta_{y2}}{234,5 + \Theta_{01}}. \quad (9\text{-}26)$$

Substituting in equation (9-4) instead of values P and $q_1$ of their value from expressions (9-26) and (9-46), we will obtain:

$$\vartheta_{y2} = \frac{P_{\text{н}}(234,5 + \Theta_{02} + \vartheta_{y2})}{[q_0 + e(\Theta_{02} + \vartheta_{y2})]\,S_{\text{к}}(234,5 + \Theta_{01})}$$

or

$$\vartheta_{y2}[q_0 + e(\Theta_{02} + \vartheta_{y2})]\,S_{\text{к}}(234,5 + \Theta_{01}) - P_{\text{н}}(234,5 + \Theta_{02} + \vartheta_{y2}) = 0.$$

after conversions we obtain quadratic equation relative to $\vartheta_{y2}$:

$$\vartheta_{y2}^2 e(234,5 + \Theta_{01}) + \vartheta_{y2}\left[(234,5 + \Theta_{01})(q_0 + e\Theta_{02}) - \frac{P_{\text{н}}}{S_{\text{к}}}\right] - \frac{P_{\text{н}}}{S_{\text{к}}}(234,5 + \Theta_{02}) = 0.$$

Let us introduce the designations:

$$A_2 = e(234,5 + \Theta_{01}), \quad B_2 = (q_0 + e\Theta_{02})(234,5 + \Theta_{01}) - \frac{P_{\text{н}}}{S_{\text{к}}}$$
$$\text{и} \quad C_2 = \frac{P_{\text{н}}}{S_{\text{к}}}(234,5 + \Theta_{02}).$$

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Then we obtain:

$$A_2\vartheta_{y2}^2 + B_2\vartheta_{y2} - C_2 = 0.$$

Solving this quadratic equation, we obtain formula for determining the average value of temperature excess of the winding of relay at a constant value of coil current:

$$\vartheta_{y2} = \frac{\sqrt{B_2^2 + 4A_2C_2} - B_2}{2A_2}. \qquad (9\text{-}27)$$

if we accept the value of the average heat-transfer coefficient $q_1$ of constant, then for the temperature of the overheating of the winding of relay we will obtain the following expression [1. 1-15]:

$$\vartheta_{y2} = \frac{(234{,}5 + \Theta_{02})\,\vartheta_1 P_{\text{н}}}{234{,}5 + \Theta_{01} - \vartheta_1 P_{\text{н}}}. \qquad (9\text{-}28)$$

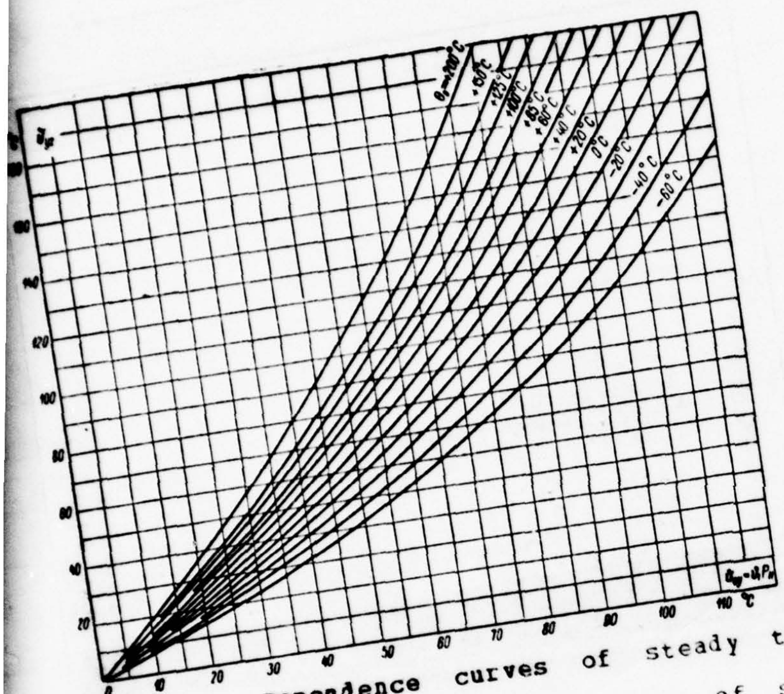

Fig. 9-7. Dependence curves of steady temperature excess of winding of relay above temperature of surrounding air from value $\vartheta_1 P_n$ at I = const.

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Figures 9-7 gives dependence curves of the overheating of the winding of the relay above the temperature of surrounding air $\Theta_{02}$ (with a constant value of coil current) when $\Theta_{01} = 20°$ C, constructed by author from temperature excess $\vartheta_{0y}$

with the aid of formula (9-28).

Heating at the constant value of coil current will occur slower, since the time constant of heating is equal to:

$$\tau_i = \frac{\tau}{1-\alpha\vartheta_{\text{oy}}}. \qquad (9\text{-}28a)$$

Simplified formulas for determining the temperature of the overheating of the winding of relay.

The determination of the temperature of the overheating of the windings of relay with the aid of formula (9.27) requires comparatively much time.

Within the limits of a change in the temperature of the overheating of the winding of relay approximately from 35 to 80°C can be obtained the considerably simpler and more convenient approximation formulas.

Figures 9-8 gives dependence curves of steady temperature of the overheating of the windings of the relay of types RES9, RES10 and RES15 from the value of coil current at the temperature of surrounding air of approximately 20°C and normal atmospheric pressure. These

curves within the limits of a change in the temperature of the overheating of windings approximately from 35 to 80°C virtually can be replaced by straight lines.

If we continue these straight lines by dotted line down before intersection with the axis of ordinates, then it is possible to see that the direct/straight for all three types relays the transverse axis of ordinates at the points $\vartheta_{10}$, which are located not far from each other.

We will take on any temperature slope of overheating within limits from 35 to 80°C two points a and b let us drop from these points perpendiculars on the axis of coordinates.

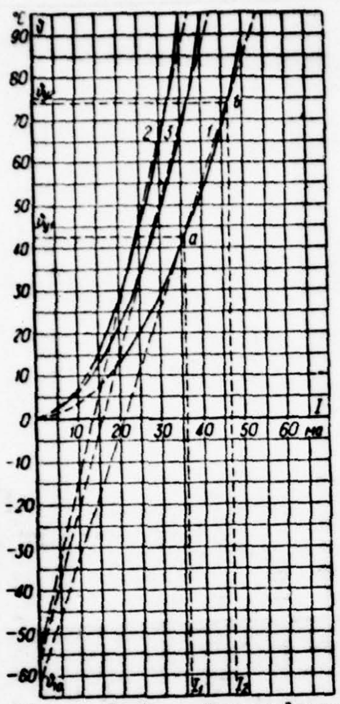


Fig. 9-8. Dependence curves of temperature of overheating of windings of relay from value of coil current when $\Theta_0 = 20°C$. 1 - relay of the type RES9; 2 - relay of the type RES10; 3 - relay of the type RES15.

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From the similarity of triangles $\vartheta_{y1}a\vartheta_{10}$ and $\vartheta_{y2}b\vartheta_{10}$ we find:

$$\frac{\vartheta_{y1}+\vartheta_{10}}{I_1}=\frac{\vartheta_{y2}+\vartheta_{10}}{I_2} \quad \text{или} \quad \vartheta_{y1}+\vartheta_{10}=\frac{I_1}{I_2}(\vartheta_{y2}+\vartheta_{10}),$$

Key: (1). or.

whence

$$\vartheta_{y1} = \frac{I_1}{I_2}(\vartheta_{y2} + \vartheta_{10}) - \vartheta_{10}. \qquad (9\text{-}29)$$

Let us multiply numerator and the denominator of the right side of the equation (9-29) on $\sqrt{R_0}$; we will obtain:

$$\vartheta_{y1} = \frac{I_1\sqrt{R_0}}{I_2\sqrt{R_0}}(\vartheta_{y2} + \vartheta_{10}) - \vartheta_{10}. \qquad (9\text{-}29a)$$

Let us designate

$$b = \frac{\vartheta_{y2} + \vartheta_{10}}{I_2\sqrt{R_0}}. \qquad (9\text{-}30)$$

Then for determining mean temperature of the overheating of the winding of relay within limits from 35 to 80°C (at the constant value of coil current and ambient temperature 20°C) we obtain from equation (9.29a) very simple formula:

$$\vartheta_{y1} = bI_1\sqrt{R_0} - \vartheta_{10} = b\sqrt{P_{m1}} - \vartheta_{10}, \qquad (9\text{-}31)$$

where $P_{m1}$ — the initial power, consumed by winding of relay at current $I_1$ and temperature 20°C (at the moment of the connection/inclusion of winding $P_{m1} = I_1^2R_0$), b - the coefficient, which characterizes construction and the size/dimensions of

relay, and $\vartheta_{10}$ - the point of intersection of the straight line of overheating with the negative participation of the axis of ordinates.

From equation (9-29) we obtain formula for determining value

$$\vartheta_{10}=\frac{\vartheta_{T1}I_1-\vartheta_{T2}I_2}{I_2-I_1}. \qquad (9\text{-}32)$$

Investigations showed that the value $\vartheta_{10}$ for the different types of miniature/small relays under normal conditions is within the limits approximately from 45.8 to 68.8°C. The average value of $\vartheta_{10}$ is equal to 57°C. The deviation of the value of $\vartheta_{10}$ of the different types of relay from average value is +11.8 and 11.2o/o (+20.7 and -19.7o/o).

At atmospheric pressure of approximately 50 mm Hg and temperature 20°C, value of $\vartheta_{10}$ for the different types of relay varies within limits approximately from 53.2 to 68.7°C. The average value of $\vartheta_{10}$ is equal to 62°C.

In Fig. 9-9 are constructed the curves of the dependences of steady temperature of the overheating of windings (with a constant value of coil current of relay)

from initial power for ambient temperature of 20°C and normal atmospheric pressure.

Within the limits of changes in the temperature of the overheating of windings from 35 to 80°C these curves on this scale grid are virtually straight lines.

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The value of coefficient b is equal to the slope tangent of these direct/straight to axis ordinates:

$$b = \frac{\vartheta_{\gamma} + \vartheta_{10}}{\sqrt{P_{\text{н}}}}. \qquad (9\text{-}30\text{a})$$

Table 9-1 gives also average values of coefficients of b and $\vartheta_{10}$ for the different types of relay at ambient temperature 20°C and two values of the atmospheric pressure: 760 and 50 mm Hg, obtained experimentally. According to these data in Fig. 9-6 are constructed the curved 3 and 4 dependences of values b and $b_1$ (led to values of $\vartheta_{10}$, with respect equal to 57 and 62°C) from the size/dimensions of the cooling surface of the winding of relay at different atmospheric pressures.

These curves are approximated by the approximation

formula:

$$b \approx b_0 S_{\kappa}^{-c}. \quad (9\text{-}33)$$

From the curves of Fig. 9-6, we find: at the normal atmospheric pressure $b_0$ = 270 and c = 0.38, and at the pressure 50 mm Hg $b'_0$ = 345 and c' = 0.38.

Consequently, at normal atmospheric pressure and temperature 20°C

$$b \approx 270 \cdot S_{\kappa}^{-0,38}. \quad (9\text{-}33a)$$

Substituting in equation (9-31) instead of b and $\vartheta_{10}$ of their value, we obtain for determining mean temperature of overheating (at the constant value of coil current of relay under normal conditions) the following approximation formula:

$$\vartheta_y \approx 270\, S_{\kappa}^{-0,38} I \sqrt{R_0} - 57 = 270\, S_{\kappa}^{-0,38} \sqrt{P_{\kappa}} - 57. \quad (9\text{-}34)$$

This formula is used within the limits of a change in the temperature of the overheating of the winding of relay approximately from 35 to 80°C at the temperature of surrounding air 20°C and atmospheric pressure 760 mm Hg. At atmospheric pressure 50 mm Hg and temperature 20°C, temperature of the overheating of winding at the constant value of coil current of relay will be equal to:

$$\vartheta_y \approx 345\, S_{\kappa}^{-0,38} I \sqrt{R_0} - 62 = 345\, S_{\kappa}^{-0,38} \sqrt{P_{\kappa}} - 62. \quad (9\text{-}34a)$$

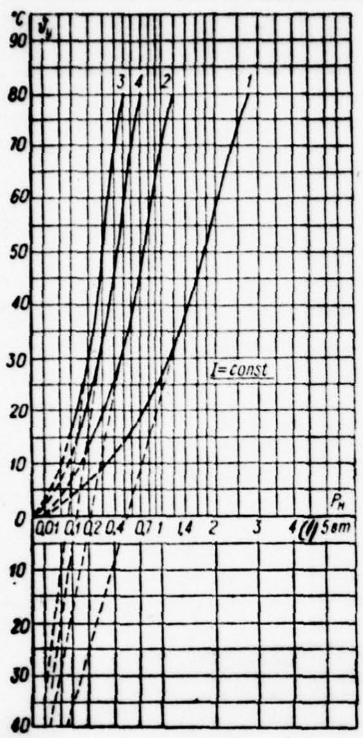


**Fig. 9-9. Dependence** curves of temperature of overheating of winding of **relay from initial** power at constant value of coil current **and** $\Theta_0 = 20°C$. 1 - relay of the type RES8; 2 - relay of the type RES9; 3 - relay of the type RES10; 4 - relay of the type RES15.

Key: (1). W.

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It is interesting to note that values of coefficients $b_0$, $b'_0$ and $\vartheta_{10}$ are respectively equal to:

$$b_0 \approx 1{,}65 a_0,\ b'_0 \approx 1{,}68 a'_0 \text{ и } \vartheta_{10} \approx 2\vartheta_{w0}. \quad (9\text{-}35)$$

and

The obtained formulas can be also used for determining the tentative value of the temperature of the overheating of the winding of relay at other temperatures of surrounding air $\Theta_{02}$, if we instead of $R_0$ supply the initial resistor/resistance of this winding $R_{02}$ (at temperature $\Theta_{02}$), calculated with the aid of formula (9-13).

9-4. Short-term connection/inclusion of winding.

If relay is included to very small time interval (measured by seconds), then dissipation of heat for this time can be considered the virtually equal to zero.

In that case it is possible to write for heating of relay the following equation:

$$Pt = Qc\vartheta,$$

where t - the heating time in s,

Q - the weight of winding in g and

c are specific heat of the material of wire in J/g•deg (for copper c = 0.391 J/g•deg).

From last/latter expression we obtain formula for determining temperature excess of the winding of relay (copper) through t s neglecting of dissipation of heat:

$$\vartheta = \frac{Pt}{Qc} = 2,56\,\frac{Pt}{Q}. \qquad (9\text{-}36)$$

Being given the value of permissible temperature excess of winding $\vartheta_м$, we find from formula (9-36) the highest efficiency which can be passed through this winding for a period of time t:

$$P_м = \frac{Q\vartheta_м}{2,56t}. \qquad (9\text{-}37)$$

Substituting for $P_м$ and Q of their value, we will have:

$$I_м^2 r = I_м^2 \rho\,\frac{l}{s} = \frac{8,9ls\vartheta_м}{2,56t},$$

whence we find formula for a maximum current density in the winding of relay (copper) upon the short-term connection/inclusion:

$$j = \sqrt{\frac{8{,}9\vartheta_{м}}{0{,}0175 \cdot 2{,}56t}} = 14{,}1\sqrt{\frac{\vartheta_{м}}{t}}. \qquad (9\text{-}38)$$

Intermittent duty.

During the intermittent duty of the winding of relay, the ultimate capacity can be raised approximately into ζ once, if the duration of operating cycle the less than time constant of heating the winding cf relay.

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Value

$$\zeta = \frac{t_a + t_b}{t_a},$$

where $t_a$ — is a duration of operating cycle (momentum/impulse/pulse) and

$t_b$ — the duration of the break between two adjacent current pulses.

In this case steady temperature excess fluctuates

between some by maximum $\vartheta_2$ and by the minimum $\vartheta_1$.

Steady temperature excess of winding in pulsed mode $\vartheta_2$ is reached when an increase in the temperature during the period of heating makes equal to a temperature decrease during cooling-down period; we have:

$$\vartheta_2 = \vartheta_y \frac{1 - e^{-\frac{t_a}{\tau}}}{1 - e^{-\frac{t_a + t_b}{\tau}}}, \quad (9\text{-}39)$$

$$\vartheta_1 = \vartheta_2 e^{-\frac{t_b}{\tau}}, \quad (9\text{-}40)$$

where $\vartheta_y$ — steady temperature excess of winding at continuous duty.

9-5. Temperature distribution according to height/altitude (thickness) of winding.

The heat flux P, passing through the thickness of insulation, is proportional to its surface of S, difference in the temperatures $(\Theta_2 - \Theta_1)$, the thermal conductivity of insulation $\lambda$ and inversely proportional to the thickness of insulation $\delta$; therefore

$$P = \frac{(\Theta_2 - \Theta_1) S\lambda}{\delta}.$$

Hence the temperature differential in the insulation

$$\Delta\vartheta = \frac{P\delta}{S\lambda}. \qquad (9\text{-}41)$$

Insulation of winding from core frequently consists of several layers of insulation between which there are fine/thin air spaces (gaps). In this case the temperature differential

$$\Delta\vartheta = \frac{P}{S}\left(\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \ldots + \frac{\delta_n}{\lambda_n}\right), \qquad (9\text{-}41a)$$

where $\delta_1, \delta_2, \ldots, \delta_n$ and $\lambda_1, \lambda_2, \ldots, \lambda_n$ —are the corresponding thicknesses and the thermal conductivities of the different layers of insulation and the air spaces.

Table 9-2 gives given data of specific heat and thermal conductivity of different materials [1. 9-10].

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It is necessary to note that the thermal conductivity of pure metals and insulation decreases with an increase in the temperature and, furthermore, it depends on porosity and degree of moistening.

The temperature of the external surface of winding is always lower than the temperature of its interior layers which do not give up directly heat into the surrounding space.

Table 9-2. Thermal characteristics of materials.

| Материал (1) | (2) Плотность γ, г/см³ | (3) Удельная теплоемкость с, дж/г·град | (4) Удельная теплопроводность λ, вт/см·град |
|---|---|---|---|
| Алюминий (5) | 2,7 | 0,92 | 2,1 |
| Медь электротехническая (6) | 8,9 | 0,39 | 4,0 |
| Латунь (7) | 8,6—8,7 | 0,38 | 1,15 |
| Бронза (8) | 8,8—8,9 | 0,42 | 0,65 |
| Сталь электротехническая Э11, Э21 (9) | 7,75—7,8 | 0,48 | 0,62 |
| Сталь электротехническая Э31, Э41 (10) | 7,65—7,55 | 0,48 | 0,35 |
| Уголь (11) | 1,5 | 0,84 | 0,0008 |
| Керамика электротехническая (12) | 2,3—2,7 | 1,0—1,2 | 0,011 |
| Стекло (13) | 2,2—2,7 | 0,64—0,85 | 0,009 |
| Пластмасса (К-18, К21-22) (14) | 1,3—1,5 | 1,5 | 0,0015 |
| Гетинакс, текстолит (15) | 1,3—1,4 | 1,25—1,65 | 0,0017 |
| Бумага (16) | 0,9 | 1,68 | 0,0007 |
| Бумага кабельная сухая (17) | 0,7—0,8 | 1,5 | 0,0013 |
| Хлопчатобумажная ткань (18) | — | — | 0,007 |
| Нить хлопчатобумажная пропитанная (19) | 1,1—1,25 | 1,8 | 0,002 |
| Лакоткань (20) | 1,1—1,35 | 1,7 | 0,0018 |
| Стеклолакоткань (21) | 2,25 | 0,8—0,9 | 0,009 |
| Фторопласт-3 (22) | 2,1 | — | 0,0007 |
| Фторопласт-4 (23) | 2,1—2,2 | — | 0,0022 |
| Ацетилцеллюлозная пленка (23) | 1,1—1,3 | — | 0,0017 |
| Слюда (24) | 2,8—3,0 | 0,8—0,9 | 0,0036 |
| Асбест (25) | 2,5 | 0,81—0,84 | 0,002 |
| Резина (26) | 1,7—2,0 | 1,7 | 0,0015 |
| Асфальт, битумы (27) | 1,1—1,3 | 0,22—0,5 | 0,0065 |
| Масло трансформаторное (28) | 0,85—0,9 | 1,8—1,9 | 0,0016 |
| Лак пропиточный (29) | 1,2 | 1,4—1,5 | 0,0025 |
| Вода при +20° С (30) | 1,0 | 4,5 | 0,006 |
| Воздух при +65° С (31) | 0,0012 | 1,02 | 0,0006 |
| Воздух в виде тонкой прослойки (32) | 0,0012 | 1,05 | 0,00025 |
| Азот (33) | 0,00125 | 1,04—1,06 | 0,00024 |
| Водород (34) | 0,000089 | 14,2—14,7 | 0,0016 |
| Гелий (35) | 0,000178 | 5,3 | 0,0014 |
| Катушка из эмальпровода непропитанная (36) | — | — | 0,0021 |
| То же пропитанная (37) | — | — | 0,0032 |

Key: (1). Material. (2). Density γ, g/cm³. (3). Specific heat s, J/g•deg. (4). The thermal conductivity λ, W/cm•deg. (5). Aluminum. (6). Copper is electrical. (7). Brass. (8). Bronze. (9). Steel electrical 311, of 321. (10). Steel electrical of 331, 341. (11). Carbon. (12). Ceramics is electrical. (13). Glass. (14). Plastic (K18, (K21-22). (15).

Getinax, Textolite. (16). Paper. (17). Paper cable is dry. (18). Cotton fabric. (19). Filament cotton saturated. (20). Varnished insulating cloth. (21). Impregnated glass cloth. (22). Polyfluoroethylene resin. (23). Is cellulose acetate film. (24). Mica. (25). Asbestos. (26). Rubber. (27). Asphalt, bitumen. (28) Transformer oil. (29). Varnish is impregnating. (30). Water with +20°C. (31). Air with +65°C. (32). Air in the form of fine/thin layer. (33). Nitrogen. (34). Hydrogen. (35). Helium. (36). Coil from enamelled wire is unimpregnated. (37). The same saturated.

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Temperature excess of interior layer of winding above the temperature of the skin of winding $\vartheta_x$ depends in essence on the thermal conductivity of winding and is $\vartheta_n$ determined by following formula [1. 9-2]:

$$\vartheta_x - \vartheta_n = \frac{p}{2\lambda_w}\left(\frac{R^2 - r_x^2}{2} + r_x^2 \ln \frac{r_x}{R}\right), \qquad (9\text{-}42)$$

where R - an outside radius of coil in cm;

$r_x$ — a radius of interior layer of winding in cm;

$p = \frac{P}{\pi l (R^2 - r^2)}$ — the losses, which are necessary per unit volume of coil in $W/cm^3$;

$l$ — length of winding in cm,

$\lambda_э = 0,6\lambda_и \frac{d}{2\delta}$ — an equivalent thermal conductivity of winding;

$\lambda_и$ — the thermal conductivity of the wire insulation of winding;

d - the wire diameter without insulation and

δ are thickness of insulation of wire.

For a decrease in the difference $\vartheta_x - \vartheta_n$ it is necessary to increase the thermal conductivity of winding. The addition of the mineral fillers increases the thermal conductivity of the saturating compounds 3-8 times. The greatest thermal conductivity have windings, saturated with bituminous oil quartz composition, which contains 30o/o of quartz flour.

For an increase in the thermal conductivity of thick multilayer insulation, it is expedient to apply the combined

insulation from many layers of fine/thin insulating sheet with laid between layers aluminum foil. The thermal conductivity of this insulation is 1.1 W/cm•deg.

The distribution of temperature excess according to the height/altitude (thickness) of the winding of the relay of the direct current of the type RKN and of the relay of alternating current of the type RC at a constant value of power input 4 W is shown in Fig. 9-10.

Great temperature excess occurs approximately in the middle of winding. On the external surface of winding, it is greater than on internal (of core); is explained this by the large heat removal through the core, especially with direct current.

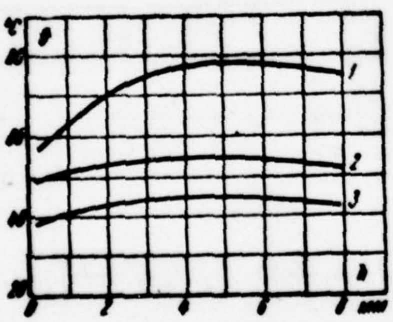

Fig. 9-10. Distribution of temperature excess according to height/altitude of winding of relay at P = 4 W. 1 - relay of the type RC with direct current; 2 - relay of

the type RC with alternating current 50 Hz: 3 - relay of the type RKN with direct current.

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With alternating current the heat is isolated not only in winding, but also in the core and other parts of the magnetic circuit, but therefore value and the character of the distribution of temperature excess according to the height/altitude of winding of the relay direct and alternating current are different.

With alternating current of relay of the type RC (curved 2) from overall power in 4 W of loss in copper they are a total of 1.34 W, remaining power (2.66 W) is scattered in steel of magnetic circuit. Great temperature excess of winding in this case is equal to 54°C, average is equal to 50°C temperature excess of core 49°C.

With the feed of relay of the type RC by direct current (curved 1) entire/all power (4 W) is scattered by the winding of relay; in this case great temperature excess of winding is 78°C, average - is equal to 69°C temperature excess of core 56.5°C.

9.6. Average heat-transfer coefficient of windings of relay.

Heat emission by hot body depends on its temperature, thermal conductivity, size/dimensions, form, character and the color of the cooling surface, and also on kind and state of the environment.

Relay is by no means the uniform body, which consists of different materials with different specific heat and different thermal conductivity.

The winding of relay consists of copper covered wire between turns of which is located the insulation and the air gaps. Furthermore, winding is separate/liberated from core by framework/body from plastic either by several layers of paper, varnished insulating cloth, fiberglass tape or synthetic film and is shielded from above by several layers of analogous insulation. Because of this the value of the average (conditional) heat-transfer coefficient (specific heat

emission) of the coils of electromagnetic relays and apparatuses of direct current is different and depends on many factors.

The heat-transfer coefficient of the coil of relay depends on its size/dimensions, character, form and the color of external surface, diameter and brand of wire, material and thickness of the layer of external and internal insulation of winding, thermal conductivity of the magnetic circuit of relay, temperature of winding, location of relay in space, the velocity of the motion of surrounding air, etc. Therefore a precise value of average heat-transfer coefficient for each special case can be determined only experimentally.

The value of the average heat-transfer coefficient of the coils of relay and apparatuses, given by the majority of authors, is within the limits from $0.94 \cdot 10^{3}$ to $1.4 \cdot 10^{3}$ $W/cm^2 \cdot deg$ [1. 4-14; 4-19; 4-21; 4-22; 4-33; 9-3].

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However, experiment shows that for the thermal designs of

miniature/small relays these values in no way suitable, since give very large errors. Thus, for instance, if we accept the value of the average heat-transfer coefficient of the equal to $1.2 \cdot 10^{3}$ to $W/cm^2 \cdot deg$, then calculated temperature excess of the winding of a miniature/small relay of the type SM, which has the cooling area 6.5 $cm^2$, greater real approximately 2.3 times. Consequently, the specific heat emission of the miniature/small relays is considerably more than normal ones. Is explained this to the fact that with the size decrease of relay the specific heat emission by convection noticeably increases.

Figures 9-11 gives average curve of dependence of the heat-transfer coefficient of the windings of valve type electromagnetic relays from the outside diameter of winding with $\Theta_0 = 20°C$ and $\vartheta$ = 50°C, constructed according to the results of the experimental investigations of author [1. 9-17].

The ratio of the length of coil to its outside diameter of all tested relay is within the limits approximately from 1 to 3. From this curve it follows that the value of the average heat-transfer coefficient of the coils of relay changes over wide limits depending on the diameter of their windings.

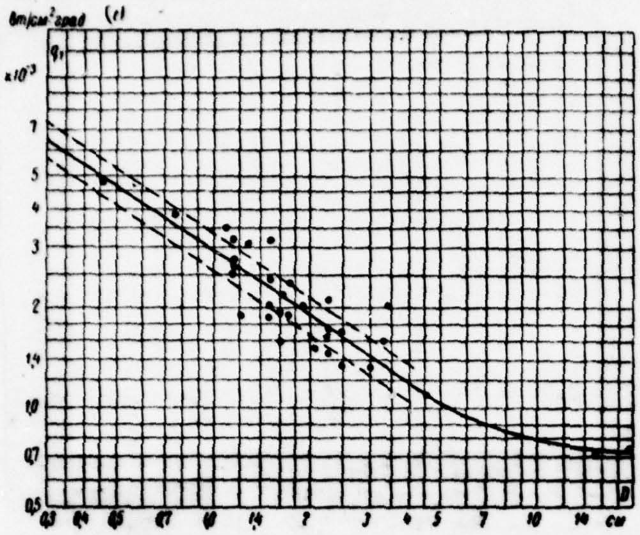


Fig. 9-11. The curves of the dependences of average heat-transfer coefficient from diameter of coil with $\Theta_0 = 20°C$ and $\vartheta$ = 50°C.

Key: (1). W/cm²•deg.

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In the range 0.3 < D < 5, curve is virtually straight line. Consequently, the dependence of average heat-transfer coefficient on the diameter cf coil within limits indicated above can be expressed by the formula:

$$q_1 = aD^b, \qquad (9\text{-}43)$$

where a and b - constant coefficients.

Coefficient a is equal to the average heat-transfer coefficient of coil by diameter 1 cm, coefficient b is equal to the slope tangent of the straight portion of curve to the axis of abscissas.

Calculating coefficients of a and b in the method of the smallest mean error, we find a = $2.98 \cdot 10^{-3}$ W/cm²•deg and b = 0.664. Substituting in formula (9-43) of the value of coefficients of a and b, we obtain:

$$q_1 = 2{,}98 \cdot 10^{-3} D^{-0.664} \approx \frac{3 \cdot 10^{-3}}{\sqrt[3]{D^2}} \text{ вт/см}^2 \cdot \text{град}. \quad (9\text{-}43\text{а})$$

w•cm²•deg

Figures 9-11 shows that the deviations of value $q_1$ from average curve of many types of relay are sufficiently considerable and reach to ±30o/o. Is explained this to the fact that the heat is abstract/removed not only by the external, but also internal surface of coil, but ratios $l/D$ and D/d are variable.

In Fig. 9-12 are constructed the curves of the dependences of average heat-transfer coefficient on the value of the calculated cooling surface of coil $S_к$ at $\Theta_0 = 20°C$ and $\vartheta$ = 50°C. BY dotted line are shown the curves within limits of which varies value $q_1$ of the separate types of relay.

The deviation of value $q_1$ from average value at the majority of the types of the tested relays does not exceed ±15o/o. By crosses in curve are noted values $q_1$ for the relay, shielded by jackets (in view of a small quantity of points curved 2 it is tentative). Consequently, for the coils of relay the value of the heat-transfer coefficient of the windings of relay it is expedient to express depending on the size/dimensions of the calculated cooling surface, but not from the outside diameter of coil.

Of course, sometimes when the ratio of the length of coil to its diameter exceeds the limits of 1-3, and the construction of relay considerably differs from the normal design of valve type relay, value $q_1$ can differ from average value more than for ±15o/o.

Curve, given in Fig. 9-12, has two straight portions

with different slope angles toward the axis of the abscissas: one within limits from 1 to 80 $cm^2$ and another within limits from 200 to 5000 $cm^2$.

coefficients a and b for the first and second sections of curve, correspondingly, are equal to: $a_1 = 5.5 \cdot 10^{3}$ $W/cm^2 \cdot deg$, $b_1 = 0.315$, $a_2 = 3.1 \cdot 10^{3}$ $W/cm^2 \cdot deg$ and $b_2 = 0.19$.

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Thus, the dependence of the average heat-transfer coefficient of the windings of valve type relay (without jacket) on the cooling surface within limits from 1 to 100 $cm^2$ can be expressed by the following formula:

$$q_1 = 5{,}5 \cdot 10^{-3} S_{\kappa}^{-0{,}315} \approx \frac{5{,}8 \cdot 10^{-3}}{\sqrt[3]{S_{\kappa}}}, \qquad (9\text{-}44)$$

a within the limits of the cooling surface from 100 to 500 $cm^2$:

$$q_1' = 3{,}1 \cdot 10^{-3} S_{\kappa}^{-0{,}19} \approx \frac{3{,}3 \cdot 10^{-3}}{\sqrt[5]{S_{\kappa}}}. \qquad (9\text{-}44a)$$

During the artificial displacement/movement of air or the motion of relay, the heat emission increases. At the velocity of air motion in 4 m/s, the heat emission

increases approximately two times [1. 9-3].

The tentative value of the average heat-transfer coefficient of the windings of the relays, shielded jackets, within limits $1 < S_{\text{н}} < 100$ cm² will be equal to:

$$q_1 \approx \frac{4,7 \cdot 10^{-3}}{\sqrt[5]{S_{\text{н}}}}. \quad (9\text{-}446)$$

The windings of relay, saturated with varnishes, have a heat emission to 3-4o/o more than unimpregnated.

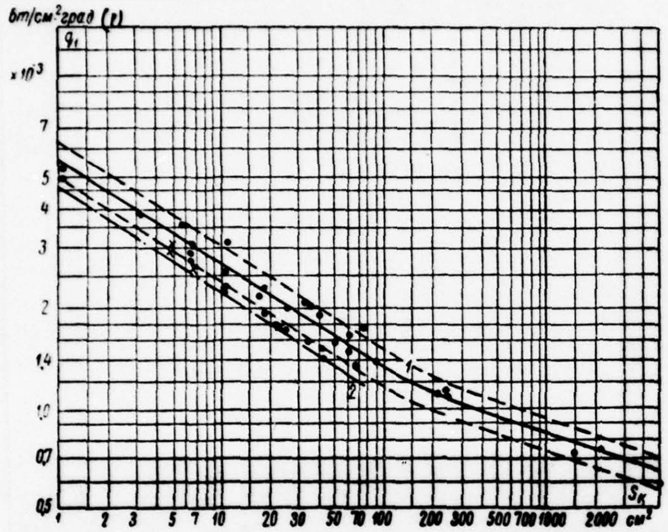


Fig. 9-12. Curved of dependences of average heat-transfer coefficient of windings of relay on calculated cooling surface of coil with $\theta_0 = 20°C$ and $\vartheta$ = 50°C. 1 - relay without jackets; 2 - relays, shielded by jackets.

Key: (1). W/cm²•deg.

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With decompression of surrounding air heat emission by

convection decreases. The value of heat emission with convection varies in proportion to to square root of air density.

Figures 9-13 gives the exemplary/approximate dependence of the heat-transfer coefficient in relative unity on the height/altitude above sea level during the free convection. As unity is accepted the heat-transfer coefficient at the level of sea.

9.7. Dependence of average coefficient of heat transfer on temperature.

As is known, the value of radiation heat-transfer coefficient and convection in general form can be expressed by the following formula

$$q = q_{л} + q_{к} = \frac{k_1}{\vartheta}\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_0}{100}\right)^4\right] + k_2\vartheta^b, \qquad (9\text{-}45)$$

where $T_1$ and $T_0$ are absolute temperatures of the body surface and surrounding air;

$k_1$ - the radiation factor of physical body (for rough

surface $k_1$ = 4.6 x 10 $^4$ W/cm$^2$ x deg$^4$);

$k_2$ - a coefficient of convection (for the vertical flat/plane wall $k_2$ = 2.55•10 $^4$); f b - the exponent whose value during natural cooling is usually accepted equal to 1/4.

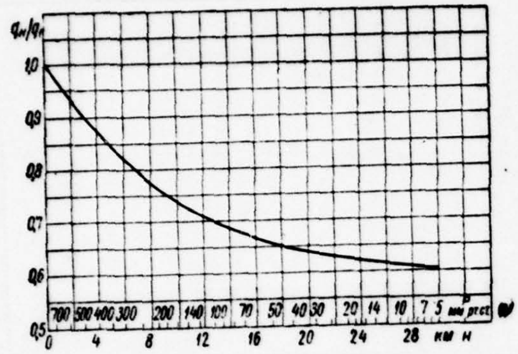


Fig. 9-13. Dependence of heat-transfer coefficient on height/altitude above sea level.

Key: (1). mm Hg.

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Values of coefficients $k_1$, $k_2$ and b depend on state and color of the cooling surface, form and size/dimensions of this surface, temperature of the body and the environment. Therefore the sufficiently precise dependence of coefficient of heat emission of body on temperature for each specific case can be obtained only experimentally. The value of the average (conditional) heat-transfer coefficient of the windings of relay and apparatuses of direct current

can be determined from experimental data with the aid of formula (9-4).

Figures 9-14 gives the curves of the dependences of the average heat-transfer coefficient of the winding of relay of the type RMU on the value of its overheating at different ambient temperatures, obtained by author experimentally [1. 9-21].

Within the limits of the temperature of overheating from 20 to 70°C these curves they in practice differ little from straight lines. The greater scatter of points with overheating less than 20°C is explained by inaccuracies of measurement of small temperature differentials.

For the development/detection of the communication/connection between of the heat emissions of the winding of relay and by temperature in Fig. 9-15 is constructed the dependence of the average heat-transfer coefficient of the winding of relay of the type RMU on the temperature of its winding.

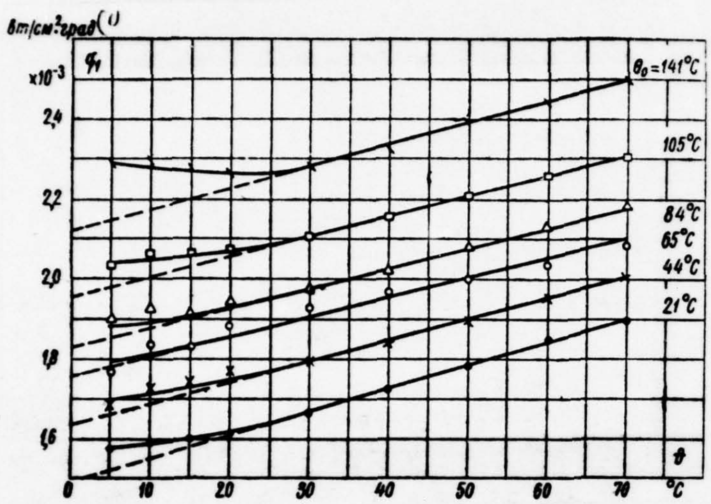


Fig. 9-14. Curved of dependences of average heat-transfer coefficient of winding of relay of type RMU on value of its overheating at different temperatures of surrounding air.

Key: (1) W/cm²•deg.

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This dependence within limits from 30 to 210°C is virtually straight line which can be expressed by the following formula

$$q_1 = q_0 + e\Theta = q_0 + e(\Theta_0 + \vartheta), \qquad (9\text{-}46)$$

where $q_0$ is the value of heat-transfer coefficient, intercept/detached on the axis of ordinate by the continuation of straight line;

e - the slope tangent of this line to the axis of abscissas.

The values of quantities $q_0$ and e for relay of the type RMU we find from Fig. 9-15:

$q_0$ = $1.422 \cdot 10^{3}$ $W/cm^2 \cdot deg$ and e = $0.00507 \cdot 10^{3}$ $W/cm^2 \cdot deg^2$.

Consequently, the value of average heat-transfer coefficient for relay of the type RMU within limits from 30 to 210°C is expressed by the following approximation formula:

$$q_1 = (1{,}422 + 0{,}00507\Theta) \cdot 10^{-3}. \qquad (9\text{-}46a)$$

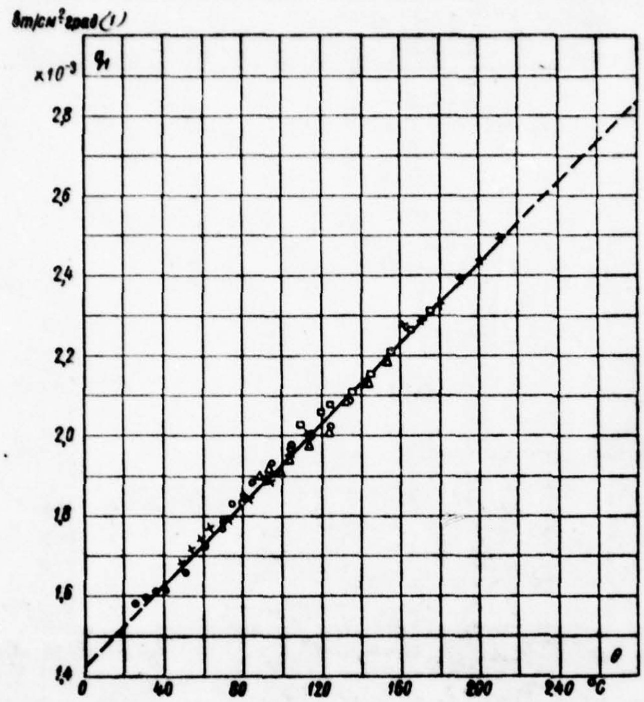


Fig. 9-15. Dependence of average heat-transfer coefficient of relay of type RMU on temperature of winding.

Key: (1). W/cm²•deg.

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The great deviation of separate values of average coefficient from straight line does not exceed 2.2o/o.

The value of the average heat-transfer coefficient at the different temperatures of the winding of relay $\theta_1$ and $\theta_2$ will be equal to:

$$q_1' = q_0 + e\Theta_1 \text{ and } q_1'' = q_0 + e\Theta_2.$$

We hence find for the average heat-transfer coefficient of the winding of relay at temperature $\theta_2$ the following expression:

$$q_1'' = q_1' + e(\Theta_2 - \Theta_1) = q_1'[1 + \gamma(\Theta_2 - \Theta_1)], \qquad (9\text{-}47)$$

where

$$\gamma = \frac{e}{q_1'}. \qquad (9\text{-}48)$$

In Fig. 9-16 are constructed the curves of the dependences of the temperature coefficient of heat emission $\gamma$ on the temperature of winding for the relay of types RKN, RMU and RES10, calculated with the aid of formulas (9-46a) and (9-48).

From Fig. 9-16 it follows that the curves of coefficients $\gamma$ for the miniature/small relay of types RMU and RES10 (without jacket) very differ little from each other, but the values of coefficient $\gamma$ for relay of the type RKN are more approximately to 25o/o. A relay of the type RES10, shielded with aluminum jacket, due to the worse heat emission has approximately two times the smaller value of coefficient $\gamma$.

Within limits from 20 to 160°C these curved virtually they differ little from straight lines.

Within limits indicated above the dependence of the value of coefficient $\gamma$ from temperature for relay of the type RMU can be expressed the following formula:

$$\gamma=(3{,}45-0{,}0079\Theta)\cdot 10^{-8}. \qquad (9\text{-}48a)$$

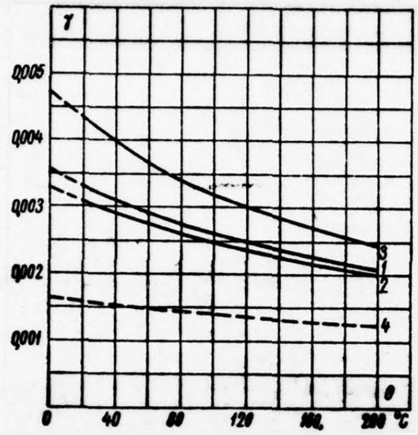


Fig. 9-16. Curved of dependences of temperature coefficient of average heat-transfer coefficient of relay on temperature of winding. 1 - relay of the type RMU; 2 - relay of the type RES10 without jacket; 3 - relay of the type RKN; 4 - relay of the type RES10 in jacket.

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Consequently, knowing the value of the coefficient of the heat emission of the miniature/small relays type RMU (without jacket) at the temperature of winding $\theta_1$, possible with sufficient for the practical target/purposes of accuracy determining the heat-transfer coefficient of these relays at another temperature of winding $\theta_2$ (within limits from 20 to

160°C) by the approximation formula:

$$q_2 \approx q_1\,[1 + (3{,}45 - 0{,}0079\Theta_1)\cdot 10^{-3}(\Theta_2 - \Theta_1)]. \qquad (9\text{-}49)$$

If the initial temperature of winding $\Theta_1$ = 50°C, then

$$q_2 \approx q_1\,[1 + 0{,}00306\,(\Theta_2 - 50)]. \qquad (9\text{-}49a)$$

Hence it follows that with an increase in temperature of the winding of small relays of the type RMU (without jacket) by 10°C coefficient of heat emission increases approximately to 3o/o.

From equations (9-46) and (9-51) we will find:

$$q_0 = q_1 - e(\Theta_0 + \vartheta) = \frac{1}{\vartheta_1 S_K} - 70e. \qquad (9\text{-}50)$$

The tentative value of quantity e for the open relay is equal $5\cdot10^{-6}$ W/cm²•deg², for miniature/small closed - $3\cdot10^{-6}$ W/cm²•deg² and for miniature closed - $4.5\cdot10^{-6}$ W/cm²•deg².

9.8. Determination of temperature excess of the windings of relay.

In Fig. 9-17 are given the curves of the dependences of the average stable excess of temperature of the windings of the different types of relay on final power in winding.

These curves within limits from zero to 70°C have comparatively small curvature. If one considers that temperature excess of windings of different copies of just one type of relay usually oscillates within limits to ±10o/o, then curves, given in Fig. 9-17, with sufficient for practical calculations accuracy can be replaced by straight lines, passing through beginning coordinates and points by curves, corresponding to 50°C. These straight lines Fig. 9-17 shows by dotted line. Consequently, for each type of relay the ratio of average temperature excess of winding to consumed power, i.e., that average being steady is exceeded the temperatures of winding at power in 1 W (specific temperature excess of windings) in the assigned range of temperature excess virtually can be considered a constant value. TP specific temperature excess of the winding of relay in deg/W, obviously, can be determined by the following formula:

$$\vartheta_1 = \frac{\vartheta}{P} = \frac{50}{P_{50}} = \frac{1}{q_1 S_K}. \qquad (9\text{-}51)$$

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Knowing specific increase in temperature of a winding of this type of relay, it is possible to find average

steady temperature excess of the winding of this relay at the assigned power within limits from zero to 70°C:

$$\vartheta = \vartheta_1 P. \quad (9\text{-}51a)$$

At the filling with the winding of entire winding space of coil, value of $\vartheta_1$ is virtually constant for each type of relay; it changes within small limits depending on diameter, the brand of wire, on material and thickness of the layer of the insulation between the winding and the core and of thermal conductivity of external shell of coil. Therefore $\vartheta_1$ with complete coil it is a thermal characteristic of this type of relay, which determines the heat emission of the latter during the steady-state conditions/mode.

At filling of entire winding space, value $\vartheta_1$ of the different types of relay is different and depends on the size/dimensions of the cooling surface of coil.

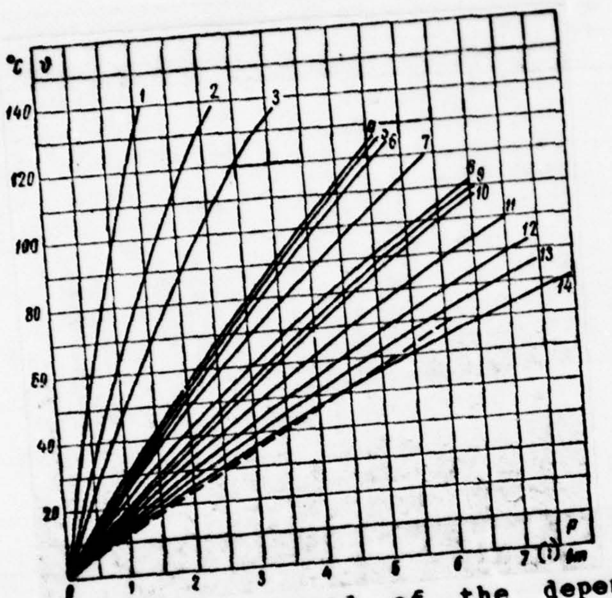


Fig. 9-17. Curved of the dependences of the averaje excess temperature of the windings of the relay of different types on that which was conducted power at $\theta_0$ = 20°C. 1 - type RES10; 2 - type RES9 and RSM; 3 - type RES6, 4 - type RMUG; 5 - type RSC -52; 6 - type RS-13; 7 - type RMU; 8 - type RS-52; 9 - type rkm-1; 10 - type rkmp-1; 11 - type MKU-48 (without cap/hood); 12 - type RKMP; 13 - type RPN; 14- type RKN and REN17.

Key: (1). W.

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Fig. 9-18 gives dependence curve specifically of temperature excess of winding from value $S_K$ at $\Theta_0$ = 20°C, on tripled by author experimentally. By dotted line are shown the limits of the probable deviations of value $\vartheta_1$ of the separate types of the relays, which have different construction.

Within limits from 1 to 100 cm³ dependence of $\vartheta_1$ on the value of the calculated cooling surface is virtually straight line and can be expressed by the following formula:

$$\vartheta_1 = (200 \div 260) S_K^{-0,73} \approx 225 S_K^{-0,73}. \quad (9\text{-}52)$$

It is consequent, average increase of the temperature of winding of relay at the steady-state conditions/mode in range indicated above $S_K$ leads equally to:

$$\vartheta \approx 225 P S_K^{-0,73} \approx \frac{240P}{\sqrt[4]{S_K^3}}. \quad (9\text{-}53)$$

Within the narrower limits of value $S_K$ from 15 to 100 cm², average temperature excess of winding can be expressed more convenient for calculations by the formula:

$$\vartheta \approx \frac{(165 \div 200)P}{\sqrt[4]{S_K^3}} \approx \frac{180P}{\sqrt[4]{S_K^3}}. \quad (9\text{-}53a)$$

For superminiature relays, which have value $S_K$ within limits from 1 to 15 cm²,

$$\vartheta \approx \frac{(180 \div 220)P}{\sqrt[4]{S_K^3}} \approx \frac{200P}{\sqrt[4]{S_K^3}}. \quad (9\text{-}53b)$$

The values of specific temperature excesses, value of the cooling surfaces of coil (with filling of entire

winding space) and constants of the time of heating the different types of relay are given in table 9-3.

If relay is fastened on metallic board, then temperature excess of its winding decreases due to supplemental heat removal through plate; then, for example, overheating of the winding of relay of the type RKN, fastened on steel plate with thickness 3 mm, decreases approximately by 15o/o.

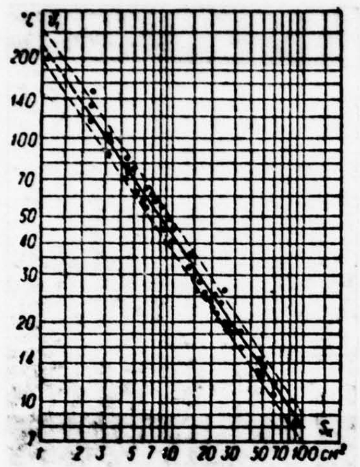

Fig. 9-18. Curved of the dependences of the specific excess of average temperature of the winding of relay on calculated cooling surface.

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Dependence of of excess temperature of windings from weight and space of relay.

During the design of the new types of electromagnetic relays, and also for determining the overheating of the existing constructions it is very important to know (at

least tentatively) the dependence of temperature excess of winding, and also as the time constant of heating relay on its weight or size. of course, this dependence of the different constructions of relay will have different character; therefore measurements were carried out on more or less uniform constructions of relay.

Figures 9-19 and 9-20 gives dependence curves of specific temperature excess of the winding of valve type electromagnetic relays from their weight and space, obtained experimentally. The relation of the length of core and to its diameter of all tested relay was within the limits approximately from 3 to 8, while the ratio of the weight of relay to its space from 1.5 to 2.0.

In Fig. 9-19 and 9-20 it follows that the dependences of specific temperature excess of windings from weight and space of relay in logarithmic scale are virtually straight lines.

The dependence of average temperature excess of winding from the weight of relay within limits from 1 to 500 g can be expressed by the following approximation formula:

$$\vartheta \approx (230 \div 350) PQ^{-0,66} \approx 285 PQ^{-0,66}. \qquad (9\text{-}54)$$

Table 9-3. Specific temperature excess and constant time of heating the relay

| (1) Тип реле | (2) Вес Q, г | (3) Атмосферное давление | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 760 мм рт. ст (4) | | | | | | 50 мм рт. ст. (4) | | | |
| | | $S_K$, см² | $\vartheta_1$, °C | 28,5°C $a'$ | $\tau$, мин (5) | $\tau_u$, мин (5) | $\tau_0$, мин (5) | $\vartheta_1$, °C | 31° C, $a'$ | $\tau_u$, мин (5) | $\tau_0$, мин (5) |
| РКН | 290 | 60,2 | 11,4 | 34,5 | 12,3 | 10 | 17,4 | 16,4 | 42,4 | 15 | 27,7 |
| РКМП | 190 | 46,9 | 13,1 | 37,2 | 11,0 | 9,2 | 15,2 | 20,0 | 47,4 | 14,5 | 25 |
| РПН | 220 | 50,9 | 13,5 | 37,6 | 9,2 | 7,7 | 12,1 | 18,5 | 45,6 | 12,1 | 20 |
| РЭС14 | 170 | 48,1 | 14,3 | 38,9 | 10,8 | 8,8 | 14 | 20,6 | 48,1 | 12,5 | 21 |
| РКМ-1 | 112 | 34,9 | 19,5 | 45,4 | 8,6 | 7,2 | 11,0 | 26,0 | 54,0 | 8,8 | 15,1 |
| ТКД12ПД | 200 | 26 | 19,9 | 45,8 | 9,8 | 8,0 | 17,5 | 22,3 | 50,0 | 15,2 | 24,2 |
| РСЧ-52 | 110 | 27,5 | 26,8 | 53 | 10,6 | 8,8 | 13,8 | 37,8 | 65,1 | 13,5 | 23 |
| РС-52 | 90 | 27,5 | — | — | 6,2 | 5,2 | 8,7 | — | — | — | — |
| РМУ | 70 | 22,6 | 22,3 | 48,5 | 7,7 | 6,4 | 9,5 | 37,1 | 64,3 | 11,8 | 16 |
| РМУГ | 160 | 22,6 | 26,1 | 52,4 | 7,0 | 5,8 | 11,8 | 33,3 | 61,1 | 11 | 16 |
| РЭС8 | 110 | 18 | 22,3 | 48,5 | 8,1 | 6,6 | 10,6 | 31,1 | 59 | 10 | 15 |
| ТКЕ52ПД | 90 | 15 | 29,2 | 55,4 | 7,3 | 6,0 | 10,0 | 31,3 | 60 | 8,0 | 14,5 |
| РЭС6 | 32 | 10,2 | 44,6 | 68,6 | 5,1 | 4,3 | 7,2 | 66,8 | 86,5 | 6,7 | 10,3 |
| РЭС22 | 32 | 9,6 | 49,5 | 72,2 | 6,1 | 5,0 | 6,6 | 67 | 87 | 7,0 | 10,2 |
| ТКЕ21ПД | 35 | 8,7 | 50,5 | 73 | 5,6 | 4,6 | 7,3 | 58 | 81 | 6,0 | 10 |
| РЭС9 | 20 | 7,6 | 57,4 | 77,6 | 4,9 | 4,1 | 7,0 | 82,7 | 96,3 | 6,5 | 11,5 |
| РЭС10 | 7,5 | 3,2 | 98,8 | 102 | 3,5 | 2,9 | 4,5 | 140 | 125 | 4,4 | 6,2 |
| РЭС15 | 3,2 | 2,4 | 135 | 119 | 2,3 | 1,9 | 3,1 | 194 | 148 | 3,6 | 5,7 |

Key: (1). Type of relay. (2). Weight Q,g. (3). Atmospheric pressure. (4). mm Hg. (5). min.

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)

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UNCLASSIFIED FTD-ID(RS)T-0124-78-PT-2 NL

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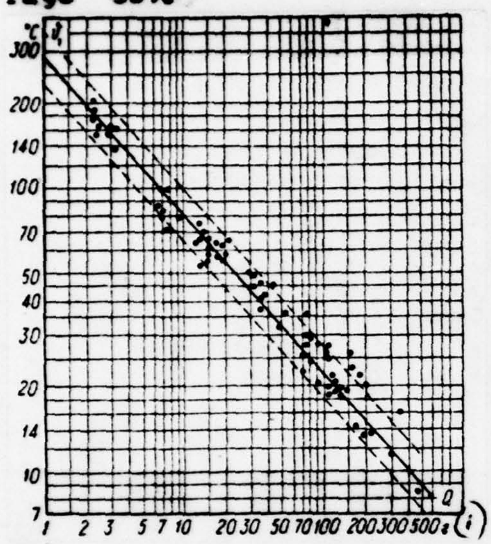


Fig. 9-19.

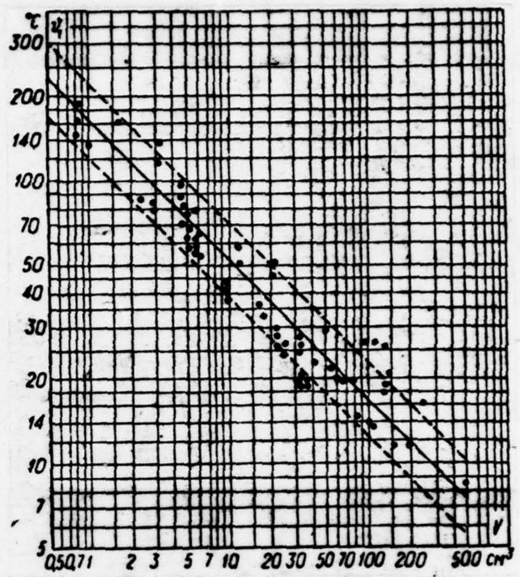


Fig. 9-20.

Fig. 9-19. Dependence curves of specific excess of mean temperature of winding from the weight of relay.

Key: (1). g.

Fig. 9-20. Dependence curves of specific excess of mean temperature of winding from space of relay.

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Within the narrower limits of the weight of relay from 70 to 500 g, the mean temperature excess of the winding of relay is expressed more convenient for calculations by the formula:

$$\vartheta \approx \frac{(185+275)P}{\sqrt{Q}} \approx \frac{225P}{\sqrt{Q}}. \qquad (9\text{-}54a)$$

For the miniature relay, which have weight from 2 to 70 g, the mean temperature excess of winding is equal to:

$$\vartheta \approx \frac{(225+275)P}{\sqrt{Q}} \approx \frac{245P}{\sqrt{Q}}. \qquad (9\text{-}54b)$$

The dependence of average temperature excess of winding from the space of relay within limits from 0.7 to 500 cm³ can be expressed by following shape:

$$\vartheta \approx \frac{(120+220)P}{\sqrt{V}} \approx \frac{160P}{\sqrt{V}}. \qquad (9\text{-}55)$$

Figures 9-21 gives the curve of the dependence of the mean heat-transfer coefficient of winding from the weight of relay. In the apparitors of the weight of relay from 1 to 500 g value of $q_1$ it is expressed by approximate formula:

$$q_1 \approx 5{,}6 \cdot 10^{-3} Q^{-0{,}235} \approx \frac{5{,}8 \cdot 10^{-3}}{\sqrt[4]{Q}}. \qquad (9\text{-}56)$$

9-9. Permissible operating temperature of the windings of relay.

The greatest permissible temperature of winding at the continuous operation of relay is determined by the physical

properties of the materials, used for insulation of wire, framework/body and contact system. The materials, used for insulation of electrical apparatuses, on the value of long permissible working temperature are subdivided into "classes of heat resistance.

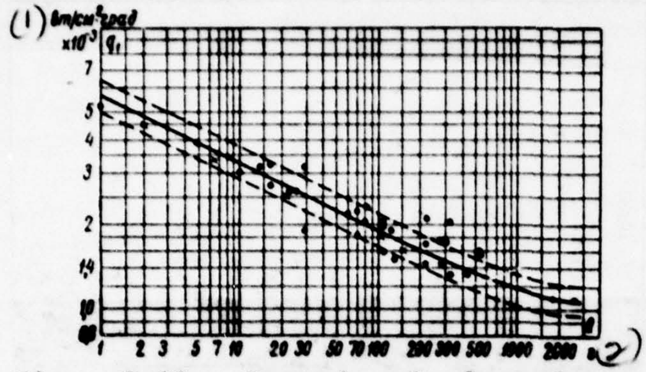


Fig. 9-21. Curved of dependence of average heat-transfer coefficient of winding on weight of relay with $\theta_1$ = 20°C and $\theta_1$ = 50°C.

Key: (1). W/cm²•deg. (2). g.

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Heat resistance is called the ability of insulation and articles without harm for them to withstand for a long time the effect of high temperature, and also its abrupt changes.

Table 9-4 gives the designations of the classes of heating stability and the corresponding values of the highest time of permissible operating temperature of

insulation provided by project GOST [99sp04 - All-union State Standard] by the tentative standard of international electrical engineering board (IEC [MЭK - International Electrotechnical Commission]).

To class A are related fibrous materials on the base of cellulose (wood, paper, cardboard, fiber, cotton filament, hydracellulose and acetylcellulose filament), the natural silk and polyamide fiber, saturated with oil, oil-resin and to that similar varnishes, and also insulation of enamelled wires on the base of oleoresinous varnishes.

To class Y, are related unimpregnated fibrous insulation of class A.

The greatest possible ambient temperature is accepted equal to +40°C.

Consequently, with insulation of class A prolonged incrase of the temperature of winding must not be more 65°C, with unimpregnated insulation of class Y greater than 50°C.

To class E, are related the plastics on phenol-formaldehyde and melamine-formaldehyde resins with the cellulose filler: getinax, Textolite, triacetate cellulose film, polyethylene terephtholate also insulation of enamelled wires on the base of polyvinylformalene varnishes.

Fiberglass materials, mica and asbestos, saturated or cement/glued with varnishes or the compounds of the usual heating stability (on the base of drying oils, bitumens, shellac, bakelite, etc.) of impregnated glass cloth, micanites, etc. They are related to class B.

To class F, belong the materials, which consist of TITLE mica, fiberglass, sbestos and so forth, saturated or glued with the varnishes it is increased eat resistance (polyurethane, poxy the like). In class H enter the materials of class B, but saturated ith organosilicon compositions.

In to class C belong inorganic unimpregnated materials: mica, Mycalex, glass, ceramics, quartz and combinations from these materials. From organic substances to class C it is related polytetrafluoroethylene (fluoroplast-4).

Table 9-4. Heat resistance of insulation.

| Класс нагре-востойкости (1) | Допустимая рабочая тем-пература, °C (2) |
|---|---|
| Y | 90 |
| A | 105 |
| E | 120 |
| B | 130 |
| F | 155 |
| H | 180 |
| C | > 180 |

Key: (1). Class of heating stability. (2). Permissible operating temperature, °C.

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For the windings of relay, largely is applied red copper wire with enamel insulation, is considerably thinner wire with silk, paper or fiberglass insulation.

Wire with enamel insulation of the brand PEL has great application/use, but can long be operated only at temperature not above 105°C.

New enamelled cables on synthetic polyvinylacetalene varnishes (Viniflex (brand PEV) and metalvin (brand PEM)) allow/assume prolonged operation at the temperature of winding to 125°C. Enamelled wire on polyurethane varnishes they have heating stability 150-160°C.

Enamelled wire on the modified polyether/polyester varnishes they can long work at temperatures to 180°C (brand PETV); they have the increased sensitivity to thermal shocks.

Polyimide varnish and enamel laquers on the base of suspension from the copolymers of teflon possess prolonged heating stability to 250°C. Wires with fiberglass insulation, the saturated with organic varnish brands PSD, can long work at temperature to 170°C and it is short-term - to 250°C.

Wires with single-layer fiberglass insulation, the saturated with silicon varnishes brands PSOT, and from two-layered - the brand PSDK and PSDKT, can be operated several hundreds of hours at temperatures respectively to 250-350°C, but they have relatively high thickness of insulation (0.12-0.18 mm).

The oxidized aluminum wire has heat resistance to 400°C, but the specific resistor/resistance of aluminum is 1.65 times more than copper. Furthermore, oxide insulation

possesses small dielectric strength (150-200 V), due to the very small thickness of oxide layer, and to increased gygroscopicity. Therefore oxide insulation must be saturated with suspensions on the base of teflon. Heating stability of penetrated oxide insulation to 250°C. For the formation/education of oxide insulation, copper wires must be covered with the thin layer of aluminum.

Higher temperatures, to 300°C, maintain/withstand the wires, covered with the continuous layer of heat-resistant glass. These wires can be made by diameter from 0.002 to 0.12 mm; the thickness of their insulation 0.010-0.025 mm, breakdown voltage are more than 1000 v. However, the winding/coil of wires from glass insulation can be done only in hot state, with the preheating of framework/body to temperature approximately 500°C [9-18].

Foreign firms advertise for prolonged operation at temperature to 300°C wire of the brand "Sechos" with the very thin layer of ceramic insulation which is applied to wires from solution/opening with the aid of electrophoresis. Ceramic insulation is saturated with suspensions on the base of teflon or organosilicon connections [9-9, 9-11, 9-19].

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The jaws of coils, insulating plates between contact springs, and insulating bushes (pushers) are manufactured mainly from getinax or Textolite. Based by relay, coil forms, separator and other insulating parts are manufactured from plastic.

The heat resistance of getinax is equal to 150°C, but at temperature above 100°C getinax changes in the course of time its size/dimensions (it shrinks). Heat resistance of Textolite is 125-135°C. Permissible working temperature of getinax and Textolite is equal to 120°C. Parts from getinax and Textolite for protection from humidity must be covered with bakelite varnish with the polymerization of the latter. For the production of the relays, intended for operation at elevated temperatures, are applied: the fiberglass laminates, pressing plastics (molding powders) with inorganic fillers and organic or silicon bonding agents, ceramics and glass.

Fiberglass laminate with the organic bonding agent of brands ST and STU has heat resistance 180-200°C and can be operated at temperature of 130°C (class B). Fiberglass laminate with silicon binder (brands STK-41 and STK-41

EP) has heat resistance more than 250°C and can long work at temperature of 180°C (class H). The heat resistance of plastics with organic fillers K-21-22, K-211-2, K-18-2, K-114-35 and others - 100-130°C; they can work at temperatures of 90-105°C (class A).

Plastics with the mineral fillers and by organic inders FKM-10, FKPM-15 (K-120-38), phenolite-4 (K18-36), etc. they have heat resistance 120-250°C and they can for long time work at temperatures of 110-130°C (class E and B). For operation under conditions of pistons into molding powders, are introduced fungicides.

Inorganic-reinforced plastics (asbestos, quartz flour, fiberglass) and organosilicon bonding agent K-71, KMK-218 and K-41-5 have heat resistance more than 250°C and can be operated at temperature of 180°C (class H) [9-13, 9-14, 9-15].

Insulation of separate windings from each other and from core is realized usually by the cable paper, varnished insulating cloth or the lacquered paper. For insulation of heat-resistant, hardly are applied the planks from synthetic materials (teflon) or fiberglass tape. For the saturation of

windings, usually is applied bituminous-oil varnish 447 (varnish 458) or glyptal-oil varnish 1154 (GF-95). These varnishes badly/poorly dry and insufficiently are cemented well windings from wire with enamel insulation. New phenoalkylide varnishes (ARB-1 and AF-17) are free from these deficiency/lacks and can be recommended for the saturation of the windings of the relays, working at temperature to 120-130°C.

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At higher working temperatures for the saturation of windings are applied organosilicon varnishes EF-3, FG-9, K-47, K-55 and K-57, that are characterized by the good power of impregnation, high heating stability and good water resistance. The windings, saturated with organosilicon varnishes, can long be operated at temperatures to 180°C.

During the short-term conditions/modes of the windings, saturated with the varnish K-47, withstand temperatures to 200-220°C saturated with the varnishes K-55 and K-57 to 250-300°C.

The fundamental characteristics of some insulation, used for the production of relay, are given in table 9-5.

Table 9-5. Properties of insulation.

| (1) Характеристика | (2) Единица измерений | (3) Прессовочные пластмассы | | | | | | | | | | | | (4) Гетинакс | | (5) Текстолит | (6) Стеклотекстолит | | (7) Стекла | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | К18-2 | К21-22 | К114-35 | ФКПМ-15 | (8) Фенолит-4 (1-18-36) | ТВФЭ-2 | (9) Асбодин | АГ-4в | КМК-218 | КМК-9 | КМС-9 | К41-5 | А | Вс | Б | СТ | СТК-41 | (10) твердые | (11) мягкие |
| (12) Плотность | (13) г/см³ | 1,33 | 1,35 | 1,8 | 1,6 | 1,8 | 1,8 | 2,0 | 1,7–1,8 | 1,8–2 | 2,0 | 1,6–2 | 1,8 | 1,25–1,4 | 1,3–1,4 | 1,3–1,45 | 1,7–1,8 | 1,70 | 2,2–2,7 | 2,4–4,3 |
| (14) Теплостойкость по Мартенсу | °C | 120 | 120 | 115 | 140 | 140 | 100 | 200 | > 250 | > 250 | > 250 | > 250 | > 300 | 150–170 | 150 | 150 | 180 | 300 | | |
| (15) Допустимая рабочая температура | °C | | | | | | | | 200 | 250 | 300 | | 200–300 | 105–120 | 150 | 105–120 | 130 | 160 | 450–1000 | 370–500 |
| (16) Предел прочности при статическом изгибе | (17) кГ/см² | 840 | 600 | 800 | 600 | 620 | 100 | 650 | 1000 | 300 | 300 | 500 | 500 | 1000 | 1300 | 1300 | 1200 | 1100 | 770–1120 | 700–1050 |
| (18) Удельная ударная вязкость | (19) кГ·см/см² | 4,7 | 4,8 | 5,0 | 6,5 | 4,5–6,0 | 20 | 8,0 | 30 | 4,5 | 3,5 | 20 | 29 | 13 | 30 | 25 | > 50 | > 50 | 0,17–0,50 | 0,17–0,50 |
| (20) Электрическая прочность | (21) кв/мм | 10 | 13 | 16 | 15 | 10 | 5 | 5 | 13 | 3,5–10 | 17 | 4 | 3,6 | 18–25 | 4–8 | 4–8 | 15 | 18 | 12–16 | 8–12 |
| (22) tg δ при 50 гц: | | | | | | | | | | | | | | | | | | | | |
| (23) а) в состоянии поставки | | 0,65 | 0,15 | 0,10 | — | 0,2 | 0,2 | 0,34 | 0,23 | 0,30 | 0,10 | 0,01 | — | 0,04–0,07 | — | — | 0,07 | 0,003 | — | — |
| (24) б) после пребывания во влажности 95 ± 3% | | 1,0 | 0,75 | 0,10 | — | 0,35 | 0,4 | 1,0 | — | 1,00 | — | 0,08 | — | — | — | — | — | 0,01 | — | — |
| (25) Удельное объемное сопротивление: | | | | | | | | | | | | | | | | | | | | |
| (23) а) в состоянии поставки | (26) ом·см | $10^{11}$ | $10^{13}$ | $10^{13}$ | $10^{12}$ | $10^{13}$ | $10^{13}$ | $10^{13}$ | $10^{10}$ | $10^{12}$ | $10^{13}$ | $10^{12}$ | $10^{11}$ | $10^{11}$–$10^{14}$ | $10^{10}$–$10^{11}$ | $10^{9}$–$10^{10}$ | $10^{13}$ | $10^{14}$ | $10^{15}$–$10^{17}$ | $10^{13}$–$10^{17}$ |
| (24) б) после пребывания во влажности 95 ± 3% | » » | — | $10^{10}$ | $10^{13}$ | $10^{11}$ | $10^{10}$ | $10^{9}$ | $10^{9}$ | $10^{10}$ | $10^{7}$ | $10^{11}$ | $10^{12}$ | | $10^{7}$–$10^{8}$ | $10^{7}$–$10^{8}$ | $10^{7}$–$10^{8}$ | $10^{8}$ | $10^{8}$ | — | — |
| (27) Удельное поверхностное сопротивление: | | | | | | | | | | | | | | | | | | | | |
| (23) а) в состоянии поставки | (26) ом·см | $10^{11}$ | $10^{12}$ | $10^{11}$ | $10^{12}$ | $10^{14}$ | $10^{12}$ | $10^{13}$ | $10^{14}$ | $10^{12}$ | $10^{13}$ | — | $10^{13}$ | — | — | — | $10^{13}$ | $10^{14}$ | — | — |
| (24) б) после пребывания во влажности 95 ± 3% | » » | — | $10^{10}$ | $10^{9}$ | $10^{9}$ | $10^{11}$ | $10^{9}$ | $10^{9}$ | $10^{9}$ | $10^{9}$ | $10^{9}$ | — | — | — | — | — | $10^{9}$ | $10^{9}$ | — | — |
| (28) Дугостойкость | (29) сек | 2 | 3 | 4 | 1,5 | 4 | 4 | 60 | 5 | 300 | > 300 | — | 300 | 1,5–3 | 1,5–3 | 1,5–3 | 1,5–3 | — | — | — |
| (30) Усадка | % | 0,8–0,9 | 0,6–1,0 | 0,4–0,8 | 0,6–0,8 | 0,6–0,8 | 0,2–0,4 | 0,4–0,6 | 0,03 | 0,6–1,0 | 0,6–1,0 | 0,2–0,5 | 0,2–0,8 | — | — | — | — | — | — | — |

Key: (1). Characteristic. (2). Unit of measurements. (3). Pressing plastics. (4). Getinax. (5). Textolite. (6). Fiberglass laminate. (7). Glass. (8). Phenolite-4. (9). Asbodin. (10). solid. (11). soft. (12). Density. (13). g/cm³. (14). Martens yield temperature. (15). Permissible operating temperature. (16). Limiting value of buckling

strength. (17). kgf/cm². (18). Impact number. (19). kg•cm/s,m². (20). Dielectric strength. (21). kV/mm. (22). tg α with 50 Hz. (23). a) in as-received condition. (24). b) after stay in humidity 95 + 3o/o. (25). Volume resistivity. (26). Ω•cm. (27). Specific skin drag. (28). Arc resistance. (29). s. (30). Shrinkage.

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9-10. Service life of insulation.

The service life of the materials, used for insulation of electrical devices depends on temperature, electrical and mechanical stresses (vibration), the effect of humidity, different chemical products and gases.

The service life of relay, long working with the large loads of winding, is determined by the service life of insulation. Under the prolonged influence of temperature, the insulation is abraded (it ages), loses elasticity and strength. Numerous laboratory tests showed that every 8-12°C

increases in the temperature accelerate the aging process of insulation two times. Furthermore, it is establish/installed that dielectric strength of fibrous insulation is not reduced, while it a will preserve mechanical strength. Even the completely losed its elasticity, but not having mechanical damages, insulation retains sufficiently high dielectric strength. The deprived of elasticity, dry, brittle insulation can break under the effect of vibrations and impacts. Therefore the windings of relay one should saturate.

The wear of insulation, can be judged from the loss by it of mechanical strength (tensile strength) or of decreases in dielectric strength two times.

The life of insulating materials is the function simultaneously of temperature and time, but therefore in dependence on the desired service life is permissible any temperature of insulation (not exceeding the temperature of its destruction).

The probable service life of insulation in hours can be expressed by the following equation:

$$Z = Z_0 e^{-\beta(\Theta - \Theta_n)}, \qquad (9\text{-}57)$$

where $Z_0$ - the so-called "nominal service life of insulation" at "nominal" permissible temperature $\theta_н$; $\beta$ is the coefficient, depending on the material of insulation, and $\theta$ - temperature of insulation.

For paper insulation (saturated) at nominal permissible temperature of 105°C it is possible to accept

$$Z_0 = 13000 \text{ h } (1{,}5 \text{ year}) \text{ and } \beta = 0{,}088 \text{ deg}^{-1}.$$

The curves of the dependences of the loss of elasticity (solid lines) and of the probable service life (broken with points) of saturated paper insulation on temperature are given in Fig. 9-22.

The loss of elasticity, i.e., decrease in the number of dual bends of paper insulation at temperature of 105°C is observed after only 10 days. Therefore prevailing opinion about the admissibility of the continuous operation of winding with the saturated paper insulation at temperature of 105°C incorrectly is led to a decrease in the normal service life of insulation of up to 1.5-2 years.

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If we consider the diurnal and annual fluctuations of supply voltage and temperature of the environment in the closed heated locations, then the common/general/total service life of insulation of class A, designed to the temperature in 100°C at maximum supply voltage and greatest temperature of the environment (+40°C), can be considered equal approximately to 20 years of continuous operation. In the case when in entire service life of relay the general duration of remaining on the winding on by heating does not exceed 1000 h, the permissible temperature of insulation can be raised to 135°C.

At the shorter service lives of relay, the temperature of winding theoretically can be raised still more, but virtually at temperature above 180°C insulation of class Very rapidly breaks down itself (it will be ignited).

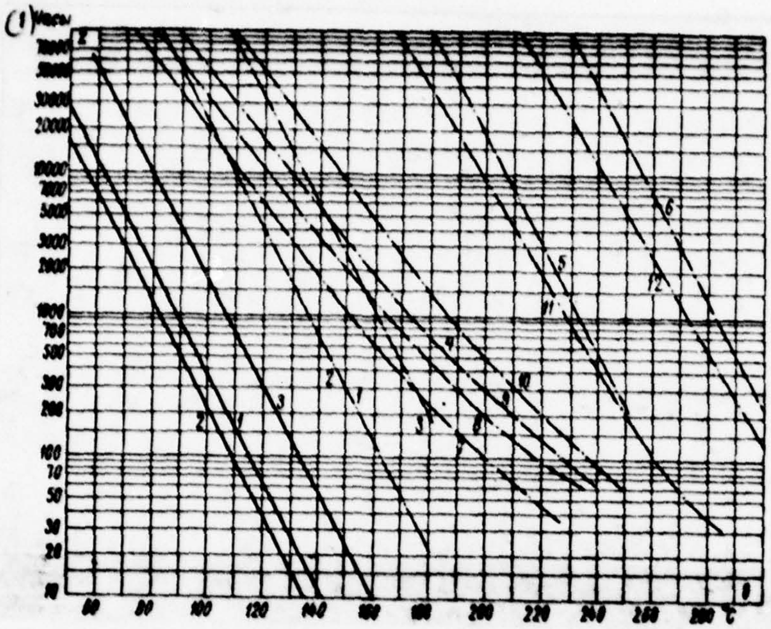

Fig. 9-22.

Fig. 9-22. Curved of dependences of loss of elasticity and probable service life wire insulation on temperature: —— is loss of elasticity of insulation; -·-·-·- probable service life of insulation. 1 - the saturated paper insulation; 2 - enamel insulation of the brand PEL; 3 - enamel insulation of the brand PEV; 4 - is enamel of insulation of the brand PETV; 5 - Fiberglass insulation of the brand PSD; 6 - fiberglass insulation of brands PSOT and PSDK; 7 - polyvinylformalene varnish; 8 - poliamide varnish; 9 - epoxy varnish; 10 - epoxy-polyester varnish; 11 - polyester-silicon varnish; 12 - insulation from polytetrafluoroethylene.

Key: (1). Hours.

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Elasticity of the film of enamel-laquers is evaluated by the ability of insulation to maintain/withstand without the formation/education of cracks and damages in coiling of wire to the cylinder of 2-3-fold heat diameter or extension to the rupture point of specimen/sample by length 250 mm of fine/thin wires (diameter 0.1-0.25 mm).

The wires, covered oil by enamel-laquer PEL), after 7 days of stay at temperature of 100°C or 24 h - at temperature of 125°C maintain/withstand coiling to the cylinder of double diameter. ¶ Synthetic namel-laquer Viniflex PEV) has large heat resistance and does not lose elasticity after 7 days of stay at temperature of 125°C or 24 h at temperature of 150°C.

If we in Fig. 9-22 apply these points and to draw through them straight lines 2 and 3, to parallel line 1 for paper insulation, then we will obtain the representation of the stability characteristics of elasticity and the probable service life the enamel wire insulation of brands PEL (2) and PEV (3).

The modified polyether/polyester varnish VEI No 124, which covered the wires of the brand PETV, barely changes its elasticity after remaining for 720 h at temperature of 180°C; after stay during 15 days at the temperature of 200°C wire, is maintain/withstood without the damage of enamel the winding on to the cruxes of 10-18-fold diameter.

It is necessary to consider that in the airtight constructions of relay at temperatures higher 130°C during the service life enamel wire insulation begins also to manifest itself the effect of vapors and gases, isolated by insulating of housing of coil and wires.

As a result of the effect of water vapors and aggressive gases at elevated temperatures, the service life of enamel insulation of wires decreases additionally.

¶ Wires with fiberglass insulation, the saturated with organic varnishes brands PSD and with the silicon varnishes of the brand PSOT, PSDK and PSDKT, can operate several hundreds of hours at temperatures with respect to 250-350°C [9-7; 9-8; 9-9].

On the basis of the given above data, in Fig. 9-22 are constructed the tentative curved (4, 5 and 6) stability of elasticity and probable period of service of heat-resistant enamel-laquers and fiberglass insulation.

Figures 9-22 gives also the average curves (7, 8, 9, 10, 11 and 12) of the heat aging (heating stability) of wires with insulation from polyvinylformalene, poliamide,

epoxy and polyether/polyester enamels and polytetrafluoroethylene, obtained by subcommittee from electrical insulation of electrical engineers's American institute [9-12].

The heating stability (thermal aging) of insulation of these wires was determined from the time, necessary at this temperature for decrease in dielectric strength of insulation to the preestablished value (obviously, 1000 V eff.).

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Data on the heating stability of the wire, isolate/insulated with polytetrafluoroethylene, are tentative.

It is necessary to note that in work under conditions of mechanical vibrations and impacts the service life of insulation decreases.

Relay usually is operated in periodic behavior, and the temperature of its insulation changes depending on the fluctuations of the temperature of ambient medium, change in the supply voltage and duration of the determination of winding for current.

The wear of insulation of relay for infinitesimal time interval will be:

$$d\zeta = \frac{dt}{Z} = \frac{1}{Z_0} e^{\beta(\Theta - \Theta_\text{д})} \cdot dt = \frac{100}{Z_0} e^{\beta(\Theta - \Theta_\text{д})} \cdot dt\,\%,$$

whence the wear of insulation for certain time interval t is equal to:

$$\zeta = \frac{100}{Z_0} \int_0^t e^{\beta(\Theta - \Theta_\text{д})}\, dt. \quad (9\text{-}58)$$

For the computation of integral, it is necessary to know the law of a change of the difference $(\Theta - \Theta_\text{д})$ in function of time.

With a constant value of the temperature of winding the wear of insulation during certain period of time t in the percentages

$$\zeta = \frac{100}{Z_0} t e^{\beta(\Theta - \Theta_\text{д})}. \quad (9\text{-}59)$$

The wear and tear of insulation of relay in percentages for some time interval, for example, for year, if for this time of relay it was included by n once to different time intervals at different temperatures, it will be:

$$\zeta_\Sigma = \sum_{i=n} \left[\frac{100}{Z_0} t_i e^{\beta(\Theta_i - \Theta_\text{д})}\right]. \quad (9\text{-}60)$$

Considering on the average $\zeta_\Sigma$ constant value, it is possible to determine the common/general/total service life

of insulation of relay in the years:

$$Z=\frac{100}{\zeta_{z}}. \qquad (9-61)$$

For providing the common/general/total service life of relay into 20 years, the wear of insulation for year $\zeta_z$ must not exceed 5o/o.

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9-11. Examples.

1. Let us determine greatest temperature of overheating of winding of relay of type RES9 under normal conditions at ambient temperature of 20°C. The operating voltage of relay is equal to $27^{+5}_{-3}$ V, winding impedance 500 ohm ± 10o/o.

From table 9-1 we find for relay of the type RES9: a = 80 and $\theta_{uo}=31°C$.

At small operating voltage 32 V and smallest winding impedance 500 - 50 = 450 ohm the temperature of the overheating of winding according to formula (9-22) will be

equal to:

$$\vartheta_y = a\frac{U}{\sqrt{R_0}} - \vartheta_{u0} = 80\frac{32}{\sqrt{450}} - 31 = 90^\circ\,C.$$

2. Let us determine greatest temperature of overheating of winding of relay of type RES9 under normal conditions at ambient temperature of 20°C. The spill current of relay is equal to 11 mA, operating current 15 mA, winding impedance 3400 ohm ± 10o/o.

From table 9-1 we find for relay of the type RES9; b = 125 and $\vartheta_{10}$ = 55.7°C.

At operating current 15 mA and greatest winding impedance 3400 + 340 = by 3740 ohm, the temperature of the overheating of winding according to formula (9-31) will be:

$$\vartheta_y = bI\sqrt{R_0} - \vartheta_{10} = 125\cdot 0{,}015\sqrt{3740} - 55{,}7 = 58{,}8^\circ\,C.$$

3. Let us determine temperature of overheating of winding of relay at voltage 30 v under normal conditions.

Winding impedance of relay at temperature of 20°C is equal to 500 ohm, the calculated cooling surface of winding 10 cm².

According to formula (9-25) the temperature of the overheating of winding will be equal to:

$$\vartheta_{y} = \frac{164U}{S_{\kappa}^{0,38}\sqrt{R_0}} - 28,5 = \frac{164 \cdot 30}{10^{0,38}\sqrt{500}} - 28,5 = 53,3^{\circ}\,C.$$

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Chapter Ten

TIME DELAY.

10-1. Transient processes upon the connection/inclusion of relay.

The transient processes, which occur in circuit with connection of the winding of relay to direct/constant voltage, it is possible to analyze with the aid of the equation:

$$U = iR + \frac{d\Psi}{dt}, \qquad (10\text{-}1)$$

where R is the effective resistance of winding, and Ψ - the flux linkage of the winding of relay with the nonpullled armature.

Equation (10-1) is written on the assumption that the phenomenon of hysteresis and eddy currents can be disregarded.

In the case of small scattering, it is possible to count that $\Psi = \Phi w$, and then let us have:

$$U = iR + w\frac{d\Phi}{dt}. \quad (10\text{-}1a)$$

for the solution to this equation it is necessary to determine the dependence of flow from time $\Phi$ = f(t).

In stable conditions/mode d$\Phi$/dt = 0 with t = $\infty$ and, therefore, $i = I_y = \frac{U}{R}$, a $\Phi = \Phi_y$.

Value $\Phi_y$, if we disregard hysteresis, it is determined in accordance with $I_y$ from the curve of the dependence $\Phi$ on aw for this type of relay with the nonpullled armature.

The character of the curves of the dependence $\Psi$ on i or $\Phi$ on aw for relay with the nonpullled and pullled armature is shown in Fig. to 10-1.

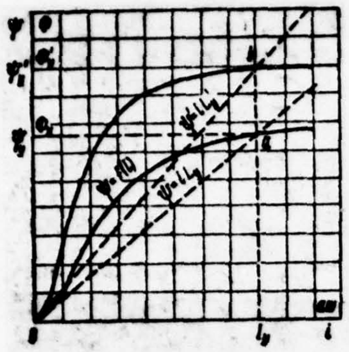

Fig. 10-1. Curved of dependences of flux linkage on current.

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Dependences of i on t and Φ on t can be found by different methods. Let us examine the solution of this problem by conditional linearization as simplest.

Let us replace nonlinear dependence of Φ on i with straight line, passing through point a, i.e., let us assume that the inductance is constant and does not depend on the current strength. In this case $\Psi = \Phi w = L_y i$, and equation (10-1a) can be rewritten as follows:

$$U = \frac{\Phi w}{L_y} R + w \frac{d\Phi}{dt}.$$

Solution to this equation gives:

$$\Phi = \Phi_y (1 - e^{-\frac{t}{\tau}}), \quad (10\text{-}2)$$

where $\tau$ - the time constant of relay with the nonpullled armature:

$$\tau = \frac{L_y}{R}.$$

Equation (10-2) gives the law of the growth/build-up of magnetic flux in the magnetic circuit (core) of relay upon the connection/inclusion of circuit, if we count the inductance of constant. Through time $t = \tau$, magnetic flux reaches $0{,}632 \cdot \Phi_y$. The steady flow value reaches virtually through time $t = 3\tau$, in this case $\Phi = 0{,}95 \cdot \Phi_y$.

The curve of dependence of $\Phi$ on t is given in Fig. 10-2. For plotting of curves of i = f(t) it is necessary for each value of $\Phi$ on curved $\Phi$ = f(aw) in Fig. 10-1 to find the appropriate values of i. The obtained thus curve of i = f(t) is shown in Fig. 10-2. It differs from the exponential $I_y(1 - e^{-\frac{t}{\tau}})$, which is constructed on this same figure.

10-2. The time for motion to start of armature.

The time delay is composed of two those who comprise:

1) the time interval, necessary for the growth/build-up of the magnetic flux of relay to the critical value by which the armature of relay begins to move and is remove/taken from back stop; this time interval is called time for motion to start $t_{\text{тр}}$ and 2) the time interval, necessary for the motion of armature from kick-off torque to closing/shorting or interrupting of the corresponding contact of relay, called the time of motion $t_{\text{дв}}$.

Thus, the time delay

$$t_{\text{ср}} = t_{\text{тр}} + t_{\text{дв}}. \qquad (10\text{-}3)$$

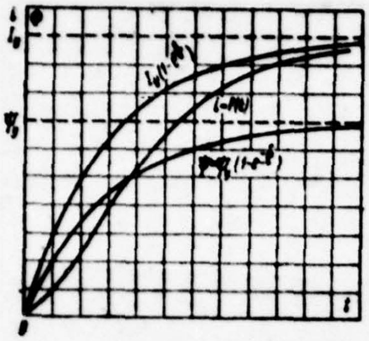

Fig. 10-2. Dependence curves of flow and current from time.

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The time of operation of different contacts of one and the same relay differently depends on the sequence of the action of these contacts. In the changing over (reversing) contacts usually breaking contact wear/operates more early than the closing.

The current (flow) of contact/start is called this value of current (flow) in the winding of the relay with which the armature of relay begins tc move and is remove/taken from back stop.

The current (flow) of function is called the value of current (flow) in winding with which the relay completely

wear/operates (they are closed all closing they are broken all the breaking contact).

Pickup current when the freewheeling escapement of the armature of relay is present, and small torque/moment of return spring can be considerably less than the spill current, but usually it differs little from spill current.

Magnetic flux in the magnetic circuit of normal (not moving rapidly) relays grows comparatively slowly; therefore eddy-current effect on triggering time can be disregarded. In this case the time for motion to start of armature with operation of relay is possible easily to determine from formula (10-2).

We assume that the armature of relay begins to move at that torque/moment when magnetic flux is achieved the flow value of function $\Phi = \Phi_c$; then time t in formula (10-2) will be equal to the time for motion to start:

$$\Phi_c = \Phi_y - \Phi_y e^{-\frac{t_{\text{тр}}}{\tau}},$$

whence

$$e^{\frac{t_{\text{тр}}}{\tau}} = \frac{\Phi_y}{\Phi_y - \Phi_c}.$$

Taking the logarithm of both parts of this equality, we find:

$$t_{тр} = \tau \ln \frac{\Phi_y}{\Phi_y - \Phi_c}. \quad (10\text{-}4)$$

Dale numerator and the denominator of the left side of equation (10-4) on $\Phi_c$, we will obtain formula for determining of the time for motion to start of the relay:

$$t_{тр}' = \tau \ln \frac{K_1}{K_1 - 1}. \quad (10\text{-}5)$$

where ln $K_1/(K_1 - 1)$ - is constant of action and $K_1$ - the safety factor along flow.

If the magnetic system of relay is not saturated, then

$$K_1 = \frac{\Phi_y}{\Phi_c} = \frac{I_y}{I_c} = \frac{AW}{AW_c}.$$

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In the majority of cases the ampere-turns of contact/start $AW_c$ can be considered equal to the ampere-turns of the function of relay (critical ampere-turns); consequently, the coefficient $K_1$ with unsaturated magnetic circuit is the safety factor on ampere turns.

The curve of the dependence of the constant of action on the safety factor is given in Fig. 10-3.

From equation (10-5) and Fig. 10-3 follows that the time for motion to start of relay increases proportional to

time constant and decreases with an increase in the safety factor.

In the case of the absence of the series-connected resistor/resistance, the time for motion to start of relay, according to formula (10-5), will be equal to:

$$t'_{\text{тр}} = \frac{L}{R} \ln \frac{K_1}{K_1 - 1}.$$

Let us multiply numerator and the denominator of constant time by $I^2$ and replace L through $K_0 w^2$; we will obtain:

$$t'_{\text{тр}} = \frac{I^2 K_0 w^2}{I^2 R} \ln \frac{K_1}{K_1 - 1} = \frac{K_0 AW_c^2 K_1^2}{P} \ln \frac{K_1}{K_1 - 1}, \qquad (10\text{-}6)$$

where P - the required power and $AW_c$ - the ampere-turns of the function of relay.

From this formula it follows that with the assigned margin of safety and the specific unamed load the time for motion to start of relay is inversely proportional to the required power.

The work of electromagnet has great value under the condition when $R_i = R_n$.

In this case values $K_0$ and $AW^2_c$, according to equations (4-52a) and (4-65), will be respectively equal to:

$$K_0 = \frac{1}{2R_i} \text{ и } AW^2 = 8F_m \mu_0 S R_i^2 = 8F_m \delta R_i.$$

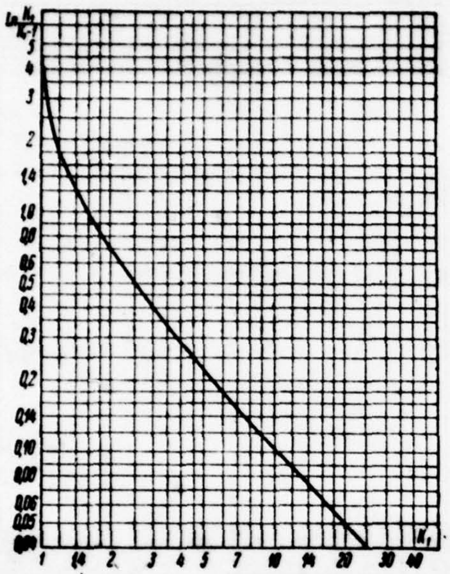

Fig. 10-3. Curved of the dependence of the constant of action on the safety factor.

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Substituting in equation (10-6) instead of $K_0$ and $AW^2$ of their values on last/latter expressions, we obtain for the time for motion to start of relay when $R_\delta = R_n$ the following expression:

$$t'_{\text{тр}} = \frac{8F\delta R_\delta}{P2R_\delta} K_1^2 \ln \frac{K_1}{K_1 - 1} = \frac{4F\delta}{P} K_1^2 \ln \frac{K_1}{K_1 - 1}$$

or

$$t'_{\text{тр}} = \frac{4A}{P} K_1^2 \ln \frac{K_1}{K_1 - 1}. \qquad (10\text{-}7)$$

With dual reserve on ampere-turns ($K_1$ = 2) time it is touched by relay, according to equation (10-7), it will be equal to:

$$t'_{\text{тр}} = \frac{4A}{P} 2,77 \approx \frac{11,1A}{P} = \frac{1,09A'}{P}, \qquad (10\text{-}8)$$

where $t'_{\text{тр}}$ - time in s, A - work in nm and A' - work in kg-cm.

the small value of the time for motion to start of relay will occur with the value of the coefficient of reserve $K_1$ = 1.4; in this case

$$t'_{\text{тр}} = \frac{4A}{P} 2,45 = \frac{9,8A}{P} = \frac{0,96A'}{P}. \qquad (10\text{-}8a)$$

If we disregard reluctance became magnetic circuits, then

$$t'_{\text{тр}} = \frac{2A}{P} K_1^2 \ln \frac{K_1}{K_1 - 1}.$$

Account of the saturation of steel of magnetic circuit.

For determining of the time for motion to start of relay taking into account the nonlinearity of magnetization curve, is most better used the method of the graphical integration.

From equation (10-1) we find:

$$dt = \frac{w}{U - iR} d\Phi.$$

If there is a curve of dependence $\Phi$ on aw, then is easy to construct dependence $\Phi$ on 1/Iw - iw. This dependence is shown in Fig. 10-4.

The time, during which the flow $\Phi$ will change from 0 to $\Phi_c$, is equal to:

$$t'_{\tau p} = \int_0^{\Phi_c} \frac{w}{U - iR} d\Phi = \frac{w^2}{R} \int_0^{\Phi_c} \frac{d\Phi}{Iw - iw}. \qquad (10\text{-}9)$$

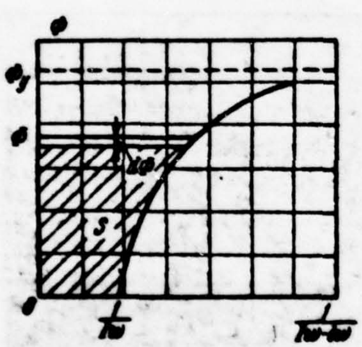

Fig. 10-4. Dependence curve of flow from value $\frac{1}{Iw-iw}$.

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This integral in Fig. 10-4 is area S, limited by curve and the axis of ordinates. The value of this area, multiplied by $w^2/R$, upon consideration of scales f and 1/iw gives the time for motion to start of relay.

Account of eddy-current effect.

The given above formulas for time for motion to start do not consider eddy-current effect, which retard the growth/build-up of the magnetic flux of relay.

Let us designate the elongation of time for motion to start, produced by eddy-current effect, by $t_в$; then the common/general/total expression for the time for motion to start of the armature of relay will take the following form:

$$t_{тр} = t'_{тр} + t_в = \tau \ln \frac{K_1}{K_1 - 1} + t_в. \qquad (10\text{-}10)$$

Timing $t_в$ analytically is extremely complex. The time constant of the circuit of normal relays is sufficiently great, and magnetic field in magnetic circuit grows comparatively slowly; therefore eddy-current effect upon connection/inclusion largely can be disregarded.

Special high-speed relays have small inductance and the high resistor/resistance of the circuit of winding; magnetic field in the magnetic circuit of these relays grows very rapidly, and therefore eddy currents have noticeable effect on the speed of operation of high-speed relays.

If one assumes that the magnetic field in the magnetic circuit of high-speed relay appears instantly, then for the calculation of the elongation of triggering time, produced by eddy currents, it is possible to use formulas (11-25) and (11-26), given it is below (in chapter eleven) during the analysis of the releasing time of relay.

10-3. Time of the motion of armature.

During the motion of armature, the inductance of relay

changes and is produced in the circuit of winding of back voltage, which decreases the current strength on section ab of growth curve of current (Fig. 10-5a).

In this case transient process in the winding of relay can be expressed by the following formula:

$$U = iR + L\frac{di}{dt} + i\frac{dL}{dt} = iR + \frac{d\Psi}{dt}; \qquad (10\text{-}11)$$

if we disregard the effect of the saturation of steel, then with motionless armature inductance can be considered constant and dL/dt = 0.

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The equation of motion of the movable system of relay is expressed in general form as follows:

$$m_1\frac{dx^2}{dt^2} + r\frac{dx}{dt} + kx + F_0 = F_9, \qquad (10\text{-}12)$$

where $m_1$ - the reduced mass of moving parts of the relay;

x - an armature travel;

r - complete specific resistance to the motion (proportional the first degree of velocity) of armature and

moving parts of the relay;

k - the given rigidity of contact and return springs;

$F_0$ - an initial value of controlling force;

$F_э$ - attracting force, acting on armature.

If we disregard initial controlling force ($F_0$ = 0) and the force of resistance to motion (rx' = 0), then the equation of motion of the armature of relay it can be written in the form

$$F_э dx = d\frac{m_1 v^2}{2} + F_м dx, \qquad (10\text{-}12a)$$

where v = dx/dt is the velocity of the motion of armature, in reference to the point of bringing mass, and

$F_м = kx$ - the force, which counteracts to the motion of armature.

Equations (10-11) and (10-12a) are nonlinear and can be solved by the approximately graphoanalytical method successive solving of [10-4, 10-6].

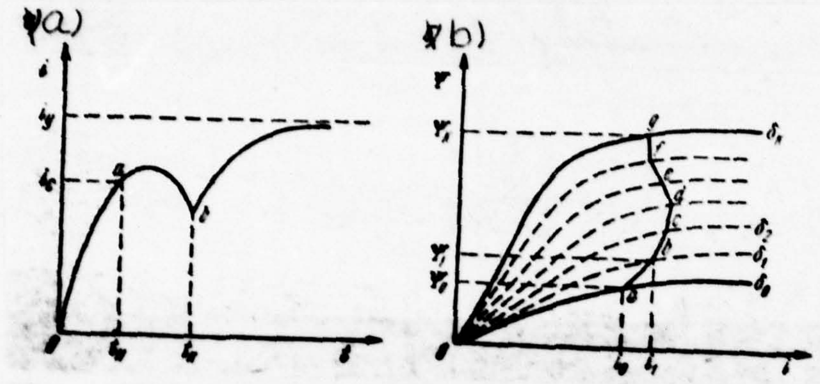


Fig. 10-5. Curved changes of coil current and current linkage during motion of armature of relay.

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Let us present equations (10-11) and (10-12) in the finite differences:

$$U = iR + \frac{\Delta\Psi}{\Delta t} \qquad (10\text{-}13)$$

and

$$F_э\Delta x = \Delta\left(\frac{m_1v^2}{2}\right) + F_м\Delta x, \qquad (10\text{-}14)$$

where $\Delta\Psi$, $\Delta t$ and $\Delta(m_1v^2/2)$ - finite differences in the flux linkage of winding, time of motion and kinetic energy of armature, which correspond to elementary armature travel $\Delta x$.

For the definition of the time of the motion of armature it is necessary to have a family of static characteristics $\Psi = f(i)$, the removed with a series values of clearance, as this is shown in Fig. 10-5b. Than more intermediate curves will be undertaken, the more precise will be the results.

From point a, which corresponds to pickup current, we carry out straight line before intersection from adjacent curve for a gap $\delta_1 = \delta_0 - \Delta x$ in such a way that $\Psi$ would increase. Then we determine area OabO, equal to work $AW_9 = F_{91}\Delta x_1$ where $F_{91}$ is an average attracting force on the section of path from $\delta_0$ to $\delta_1$. From equation (10-14) we find the velocity of armature at the end of the first section $v_1$. Value $F_M dx$ we determine from the mechanical characteristic of relay.

Set/assuming acceleration by constant, we find the time of the motion of armature on the first section:

$$\Delta t_1 = \frac{\Delta x_1}{v_{cp1}}, \qquad (10\text{-}15)$$

where

$$v_{cp1} = \frac{v_0 + v_1}{2} \approx \frac{v_1}{2}.$$

From Fig. 10-5b we find increments in the flux linkage and current on the first section:

$$\Delta\Psi_1 = \Psi_1 - \Psi_0 \text{ and } \Delta i_1 = i_1 - i_0.$$

Substituting in (10-13) values $i_{cp} = i_0 + \frac{\Delta i_1}{2}$, $\Delta\Psi_1$ and $\Delta t_1$, we check the correctness of the selection of cut ab. With the noncompliance of equality (10-13) it is selected the new direction of line ab and we repeat calculation until is satisfied this equality.

In a similar manner we find the time of the motion of armature on the second, the third and remaining sections.

The complete time of the motion of armature is equal to the sum of the times of motion on the individual sections:

$$t_{\text{дв}} = \Delta t_1 + \Delta t_2 + \ldots + \Delta t_n. \quad (10\text{-}16)$$

Figures 10-6 shows the oscillograms of current I and of the mechanogram of the motion of armature (δ) of normal, pulse and time-lag relay of the type RKN, obtained experimentally.

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Figures 10-6a shows that the time for motion to start of the tested relay of the type RKN during function was equal to 20 ms, and the time of the motion of armature 40 ms.

With release/tempering the time for motion to start of this relay was equal to 6.9 ms, the time of the motion of armature 6.2 ms the chatter time of armature 8.1 ms. The motion of armature with release/tempering has strongly damped oscillatory nature. The natural vibration frequency of armature is equal to 57 Hz, the chatter time of armature 8.1 ms.

The time of motion of armature of the pulse relay of the type RKN with grooves (Fig. 10-6b) both during the function and with release/tempering is considerably less than normal one. The frequency of its own oscillations of armature is about 165 Hz.

For time-lag relay of the type RKN (Fig. 10-6c) the time of the motion of armature with release/tempering

reaches to 40 ms. The natural vibration frequency of contact springs is within the limits approximately from 350 to 550 Hz. The fluctuations of contact springs attenuate approximately for 10-20 ms.

Approximate computation of the time of the motion of armature.

The special types of high-speed relays have the very slow speed of armature, comparatively large pole gap and armature and relatively high tension of the return spring of armature.


Fig. 10-6. Oscillograms of current and mechanogram of motion of armature of relay of type OKN: a) normal; b) pulse; c) retarded.

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In this case it is possible to assume that the torque/moment, created y attracting force $M_э$, and the reactionary torque of spring $M_п$ during the armature travel of relay virtually remain constants; then the armature of relay will complete the uniformly accelerated motion.

The equation of motion of the armature

$$J\frac{d^2\alpha}{dt^2} = M_э - M_п, \qquad (10\text{-}17)$$

where J is the moment of the inertia of armature relative to rotational axis and

$\alpha$ - the angle of rotation of armature in radians.

Integration of equation (10-17) gives:

$$\frac{d\alpha}{dt}=\frac{M_э-M_п}{J}t+c_1 \quad \text{and} \quad \alpha=\frac{M_э-M_п}{2J}t^2+c_1t+c_2,$$

where integration constant $c_1$ and $c_2$ we find from initial conditions.

With t = 0

$$\frac{d\alpha}{dt}=\omega=0 \quad \text{and} \quad c_1=0; \quad \alpha=0 \quad \text{and} \quad c_2=0.$$

Consequently,

$$\alpha=\frac{M_э-M_п}{2J}t^2,$$

whence we obtain formula for determining the time of the

motion of the armature of the relay:

$$t_{\text{дв}} = \sqrt{\frac{2J\alpha}{M_{\text{э}} - M_{\text{п}}}}. \quad (10\text{-}18)$$

At small angles of rotation, it is possible to count $\alpha \approx \delta/c_1$, where $c_1$ is a distance from the rotational axis of armature to the axis of core. Consequently, at small angles of rotation and with a constant value of resulting moment the time of the motion of the armature of relay will be equal to:

$$t_{\text{дв}} = \sqrt{\frac{2J\delta}{c_1(M_{\text{э}} - M_{\text{п}})}} = \sqrt{\frac{2J\delta}{c_1^2(F_{\text{э}} - F_{\text{п}})}} = \sqrt{\frac{2m_1\delta}{F_{\text{э}} - F_{\text{п}}}}, \quad (10\text{-}18\text{a})$$

where $m_1$ - the reduced mass of armature, equal to $J/c^2_1$.

During the determination of the complete value of reduced mass, it is necessary to consider also the reduced mass of all mobile contact springs, powered by armature.

The armature of relay usually has flat/plane or L-shaped form and simply it can be represented consisting of one or two rectangular plates on which are additionally fastened the rectangular or round plates of different size/dimensions.

The moment of the inertia of the armature of relay relative to rotational axis is equal to the sum of the moments of the inertia of its individual parts relative to this axis.

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The moment of the inertia of rectangular prism, which is turned about the axis, passing through middle of one of its lateral sides (unbalanced armature), is equal to:

$$J = \frac{m}{3}(l^2 + b^2) \approx \frac{m}{3} l^2, \qquad (10\text{-}19)$$

where m is a mass of parallelepiped, equal to its weight, divided into the acceleration of gravity , $l$ - length of parallelepiped and b - its thickness.

The thickness of armature is usually small in comparison with its length; therefore value $b^2$ in formula (10-19) can be disregarded.

The principal moment of inertia of rectangular prism, which is turned about the axis, passing through the middle of parallelepiped (balanced armature), is equal to:

$$J = \frac{m}{12}(l^2 + b^2) \approx \frac{m}{12} l^2. \qquad (10\text{-}19a)$$

The torque/moment of the inertia of rectangular prism (of rectangular plate), that is turned about the axis, not passing through this parallelepiped, it will be:

$$J = \frac{m}{12} l^2 + m\left(l_1 + \frac{l}{2}\right)^2, \qquad (10\text{-}19b)$$

where $l_1$ is a distance from rotational axis to the nearest side (beginning) of plate.

The moment of the inertia of the circular plate, which is turned about the axis, not passing through this plate,

$$J = m\left(\frac{d^2}{16} + l_2^2\right), \qquad (10\text{-}19c)$$

where d is a diameter of plate and $l_2$ - distance from the center of plate to rotational axis.

The moment of the inertia of armature can be defined experimentally, if we hang up it on knife edge or fine/thin axis in such a way that the armature would oscillate as physical pendulum.

The frequency of oscillations of this pendulum is equal to:

$$f = \frac{1}{2\pi}\sqrt{\frac{mgl_n}{J}}.$$

Hence, the moment of the inertia cf the armature

$$J = \frac{mgl_{\text{ц}}}{4\pi^2 f^2},$$

where m is a mass of armature, $l_{\text{ц}}$ - the distance of the center of gravity of armature from the rotational axis, g - the acceleration of gravity and f - the number of fluctuations of armature per second.

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If the armature of relay is not balanced and has a form of rectangular prism the rotational axis of which passes along lateral side, then according to formulas (10-18a) and (10-19) the time of the motion of this armature with a constant value of net force of attraction will be equal to:

$$t_{\text{дв}} = \sqrt{\frac{2ml^2\delta}{3c_1^2(F_э - F_п)}} = \sqrt{\frac{2Ql^2\delta}{3gc_1^2(F_э - F_п)}} = \sqrt{\frac{2Q_п\delta}{g(F_э - F_п)}}, \quad (10\text{-}18б)$$

where Q - the actual weight of armature, $Q_п$ - the given weight of armature, g - acceleration of gravity $F_э$ - attracting force of armature and $F_п$ - controlling force, created by the load of armature.

Given weight of the armature, which has the form of rectangular parallelepiped,

$$Q_n = \frac{Ql^2}{3c_1^2}.$$

If $c_1$ = $l$, then $Q_n = Q/3$.

The reduced mass of the armature, which has the form of rectangular prism,

$$m_1 = \frac{J}{c_1^2} = \frac{ml^2}{3c_1^2}.$$

In the case when $c_1$ = $l$, the reduced mass of armature $m_1$ = $m/3$.

If armature is symmetrical and has a form of rectangular prism that $c_1$ = $l/2$ and

$$m_1 = \frac{ml^2}{12c_1^2} = \frac{m}{3}.$$

R. Pik gives for the time of the motion of armature following expression [10-21]:

$$t_{\text{дв}} = \sqrt[3]{27c_w K_1^2 \left(\ln \frac{K_1}{K_1 - 1}\right) \frac{m_1 \delta^2}{P}}, \qquad (10\text{-}20)$$

where $m_1$ - the reduced mass of armature in kgf, $\delta$ - the course of armature in m, P - watts and $c_w$ - the coefficient, depending on the parameters of magnetic relay circuit.

The value of coefficient $c_w$ usually is within the limits from 1.6 to 2.7 and on the average can be accepted equal to two.

The small value of the time of the motion of armature will occur with the safety factor on spill current $K_1$ = 1.4.

Substituting in equation (10-20) the optimum value $K_1$ = 1.4 and $c_w = 2$, we obtain for the smallest value of the time of the motion of armature the following expression:

$$t_{дв.мин} = \sqrt[3]{\frac{135 m_1 \delta^2}{P}} = \sqrt[3]{\frac{135 J \delta^2}{c_1^2 P}}, \qquad (10\text{-}20a)$$

where J - the moment of the inertia of armature relative to rotational axis and

$C_1$ - distance from the rotational axis of armature to the axis of core.

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10-4. Great time delay.

The time for motion to start of relay, according to formula (10-5), is equal to:

$$t_{\text{тр}} = \frac{L}{R}\ln\frac{K_1}{K_1-1} = \frac{K_0}{C}\ln\frac{K_1}{K_1-1}.$$

For obtaining the greatest time delay, it is possible to increase time constant and to decrease the coefficient of reserve $K_1$. To avoid a decrease in the reliability of the operation of relay and stability of its parameters the value of the safety factor should not be taken less than 1.4-1.5.

Therefore for achievement of maximum triggering time, it is necessary to ensure the great possible value of the time constant of winding.

Let us replace coefficients $K_0$ and C in this equation with their values from expressions (4-50) and (6-13); we obtain:

$$t_{\text{тр}} = \frac{lhk_3}{R_M \pi \rho (D_0 + h)} \ln\frac{K_1}{K_1-1}. \qquad (10\text{-}21)$$

Disregarding scattering and the thickness of the insulation between the core and the winding, is possible to rewrite equation (10-21) as follows:

$$t_{\text{тр}} = \frac{\mu_0 \pi d_c^2 l h k_3}{4\sigma\pi\rho\,(d_c + h)} \ln\frac{K_1}{K_1 - 1} = \frac{\pi l k_3 \cdot 10^{-7}}{\sigma\rho}\left(\ln\frac{K_1}{K_1 - 1}\right)\frac{d_c^2 h}{d_c + h}. \quad (10\text{-}21a)$$

where $d_c$ is a diameter of core and

$\sigma$ - the reduced length of clearance taking into account the reluctance of steel of magnetic circuit.

Consequently, at constant values $\sigma$ and $K_1$ the time for motion to start of relay is proportional to the section of core, to the total cross section of copper of winding ($lhk_3$) and it is inversely proportional to the average length of turn $[\pi(d_c + h)]$ and to the specific resistor/resistance of wire.

If are assigned the overall dimensions of relay, determined by the outside diameter D and by the length of coil, then the diameter of core is connected with the outside diameter of coil and the height/altitude of the winding by the following relationship/ratio:

$$d_c = D - 2h. \quad (10\text{-}22)$$

Let us replace in equation (10-21) $d_c$ through (D - 2h) let us designate:

$$\varepsilon = \frac{\pi l k_3 \cdot 10^{-7}}{\sigma\rho} \ln\frac{K_1}{K_1 - 1};$$

then equation (10-21) it will be rewritten in the following form [11-5]:

$$t_{\text{тр}} = \varepsilon \frac{d_c^2 h}{d_c + h} = \varepsilon \frac{(D-2h)^2 h}{D-h}. \qquad (10\text{-}23)$$

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Let us introduce instead of the height/altitude of winding h relative value h/D; we will obtain:

$$t_{\text{тр}} = \varepsilon D^2 \frac{\left(1-\frac{2h}{D}\right)^2 h}{\left(1-\frac{h}{D}\right) D}. \qquad (10\text{-}23a)$$

In this case, if one assumes that entire space of coil occupies core ($d_c = D$ and h = 0), then the time for motion to start of relay, obviously, will be equal to zero. If we, on the contrary, to assume that entire space of coil is filled by copper (i.e. h = D/2), then the time for motion to start of relay will also be equal to zero.

The condition, under which time for motion to start will have maximum value, can be found, equalizing zero

derivative of (10-23) by h [11-5]; we have

$$\frac{dt_{\text{тр}}}{dh}=\varepsilon\frac{D-2h}{(D-h)^{3}}[(D-h)(D-6h)+h(D-2h)]=0$$

or

$$(D-2h)(4h^{2}-6Dh+D^{2})=0.$$

First solution of this expression gives D = 2h and determines the minimum of function $t_{\text{тр}}=0.$ Remaining two solutions are the square roots equation:

$$4h^{2}-6Dh+D^{2}=0.$$

Value h physically cannot be more than D; therefore maximum determines the second root of equation with minus sign:

$$h=\frac{6D-4{,}48D}{8}=0{,}19D. \qquad (10\text{-}24)$$

Substituting for D its value from (10-22), we find the advantageous relationship/ratio between the height/altitude of winding and the diameter of the core with which time for motion to start will have the maximum value:

$$h=0{,}19(2h+d_{c})$$

or

$$h=0{,}306d_{c}. \qquad (10\text{-}25)$$

The maximum value of the time for motion to start of relay can be obtained, substituting in (10-23) optimum relationship/ratios (10-24) and (10-25):

$$t_{\text{тр.макс}}=0{,}09\varepsilon D^{2}=0{,}233\varepsilon d_{c}^{2}=0{,}732d_{c}^{2}\frac{Ilk_{3}\cdot 10^{-9}}{\rho\sigma}\ln\frac{K_{1}}{K_{1}-1}. \qquad (10\text{-}26)$$

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Thus, the maximum value of the time for motion to start of relay, other conditions being equal, is proportional to section and the length of core. With the assigned overall dimensions great retarding/deceleration/delay can be reached in the case when the length of core will approach length of the magnetic circuit of relay (two-coil relay).

Figures 10-7 gives the curve of the relative time for motion to start of relay in function of h/D and $h/d_c$ with constant value D. From this curve it follows that an increase in altitude of winding double in comparison with optimum (to $h = 0{,}61 \cdot d_c$) decreases time for motion to start for 16o/o.

With a constant value of the diameter of core and under other equal conditions, the time for motion to start of relay according to equation (10-23) increases with an increase in altitude of winding, asymptotically approaching the limit:

$$t_{тр} = \varepsilon d_c^2.$$

Figures 10-8 shows the curve of the relative time for motion to start of relay in function $h/d_c$ with a constant value $d_c$. From Fig. 10-8 it follows that if the relation $h/d_c$ exceeds unit, then that is led to the very poor use of copper and an increase in the overall size of relay and required power. For an increase in the time for motion to start of relay to considerably more rational increase the diameter of core and to decrease the height/altitude of winding down to optimum value. The virtually optimum height of winding as a result of the effect of the paths of boundary/edge and lateral conductivities, apparently, is within the limits from $0{,}35d_c$ to $0{,}5d_c$.

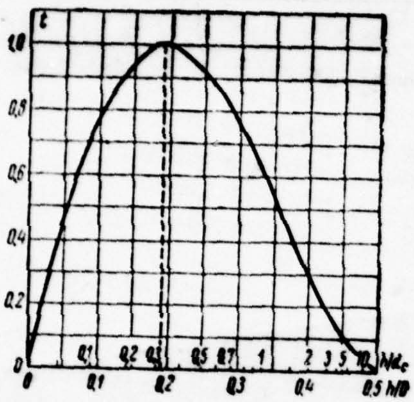


Fig. 10-7. Curved of dependence of time for motion to start of relay on ratio $h/d_c$ and h/D with constant value D.

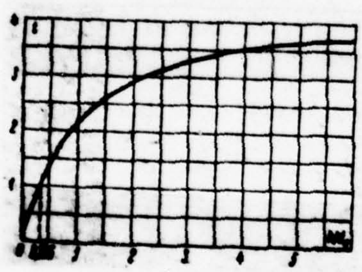

Fig. 10-8. Curved of dependence of time for motion to start of relay on relation $h/d_c$ with constant value $d_c$.

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The investigations, made by author, showed that triggering time of valve type normal (not retarded) relays with the pole piece (in ms) depending on the weight of

steel of magnetic circuit in limits approximately from 10 to 110 g can be expressed with a sufficient degree of degree of approximation by the following formula:

$$t_{cp} \approx 4Q_c^{0,9}K_1^{-1,5}m^{-0,85} \approx \frac{2,7Q_c}{\sqrt{K_1^3}\sqrt{m^3}}, \qquad (10\text{-}27)$$

where $Q_c$ is weight of steel of the magnetic circuit of relay in grams.

This formula is correct within the limits of change m approximately from 1.8 to 8 and the safety factor from 1.5 to 3.

The weight of steel of the magnetic circuit of valve type relay on the average is approximately 40o/o of total weight of relay (without jacket).

For voltage relay, workers in local circuit, m ≈ 2, and triggering time

$$t_c \approx \frac{2,7Q_c}{\sqrt{K_1^3}\sqrt{m^3}} = \frac{1,0Q_c}{\sqrt{K_1^3}}. \qquad (10\text{-}27a)$$

With dual reserve on the current of operation ($K_1$ = 2) and m = 2

$$t_{cp} \approx 0,57Q_c. \qquad (10\text{-}17b)$$

Triggering time of valve type unretarded relays, which do not have the pole piece, is approximately two times less.

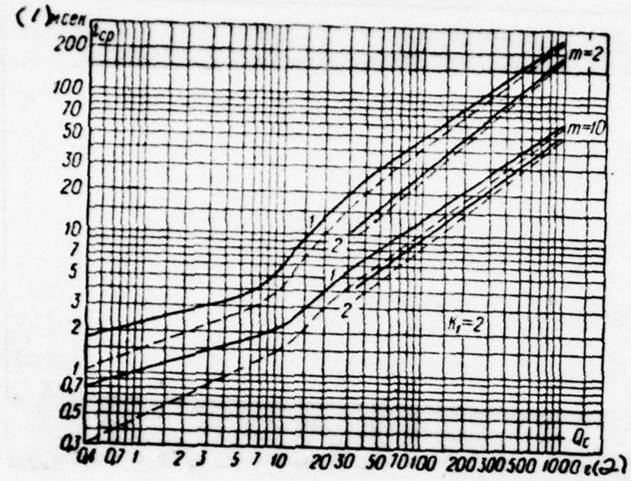


**Fig. 10-9. Curved of dependences of time delay on weight of steel of magnetic circuit. 1 - core with the pole piece; 2 - core without the pole piece.**

Key: (1). ms. (2). g.

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Figures 10-9 gives tentative dependence curves of the time delay of valve type polar (1) and without pole pieces (2) from weight stopped the magnetic circuits with dual reserve on spill current and at the values of coefficient of m = 2 and m = 10, obtained experimentally. By dotted line are shown curves for the breaking contact.

10-5. Minimum time delay.

Let us examine the time delay, connected in series with resistor/resistance $r_d$ under the condition of the constancy of the total resistance of circuit and applied voltage of battery, i.e., the constancy of the overall power of relay circuit. The time for motion to start of relay, according to formula (10-5), will be equal to:

$$t_{тр} = \frac{L}{R + r_d} \ln \frac{K_1}{K_1 - 1}.$$

Multiplying numerator and the denominator of time constant for $I^2$ and replacing L by product $K_0 w^2$, we obtain the formula, similarly to equations (10-6):

$$t_{тр} = \frac{I^2 K_0 w^2}{I^2 (R + r_d)} \ln \frac{K_1}{K_1 - 1} = \frac{K_0 A W_c^2}{P_1} K_1^2 \ln \frac{K_1}{K_1 - 1}, \quad (10\text{-}6a)$$

where $P_1$ - the total power, expended in the winding of relay and supplementary resistor/resistance.

From this formula it follows that with an increase in the safety factor at the constant value of the power input

of constant time increases, and the constant of action decreases. Consequently, at certain value of the safety factor the time for motion to start of relay will have a minimum.

For determining the condition under which time for motion to start will be minimum, we differentiate last/latter expression with respect to $K_1$ and equate derivative with zero; then we obtain:

$$\frac{dt_{тр}}{dK_1} = 2K_1 \ln \frac{K_1}{K_1-1} - \frac{K_1}{K_1-1} = 0 \quad \text{or} \quad 2\ln\frac{K_1}{K_1-1} = \frac{1}{K_1-1}.$$

Let us designate:

$$\frac{1}{K_1-1} = a;$$

then

$$\frac{K_1}{K_1-1} = 1 + a.$$

Substituting new designations in the given above equation, we obtain:

$$2\ln(1+a) = a \quad \text{or} \quad 1 + a = e^{\frac{a}{2}},$$

whence

$$a = \frac{1}{K_1 - 1} = 2{,}5.$$

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It is consequent, the maximum speed of the function (contact/start) of relay in the assigned case will occur with the safety factor along flow (on ampere-turns), equal to:

$$K_1 = \frac{\Phi}{\Phi_c} = \frac{1 + 2{,}5}{2{,}5} = 1{,}4. \qquad (10\text{-}28)$$

Figures 10-10 gives the curves of the dependences of triggering time on the coefficient of reserve $K_1$ for relay of the type RKN at different power. For a comparison in the figure, is constructed the theoretical curve, designed according to formula (10-6a).

From the given curves it follows that with an increase in the power the sharpness of the minimum decreases and its position is moved to the side of the large values $K_1$. At the power 0.5 W, conducted to relay circuit, the minimum occurs about value $K_1$, equal to 1.6, while at power in 4.0 W - approximately 2.5.

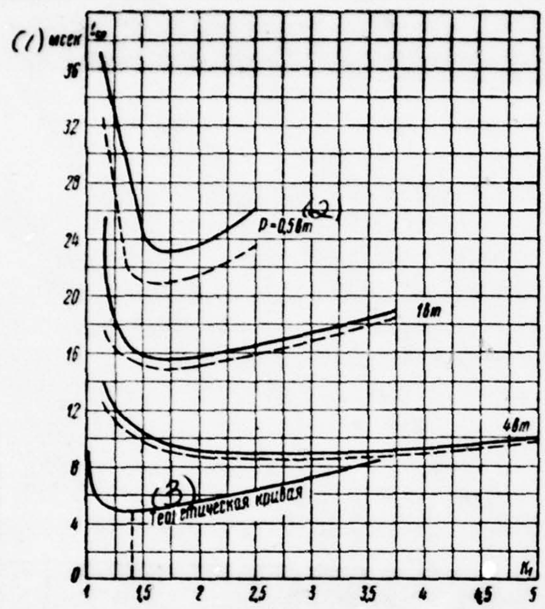


Fig. 10-10. Curved of dependences cf time delay of type RKN on coefficient of reserve (on ampere-turns) with constant value of power input.

Key: (1). ms. (2). W. (3). Theoretical curve.

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The displacement/movement of the minimum of triggering time is explained to the fact that with an increase in the power speed of response of relay increases and the

time of the motion of armature, and also eddy currents (the not taken into consideration during conclusion/derivation conditions for the minimum) more powerfully affect the operating time of relay.

The sharpest decrease in triggering time is observed with the low safety factors on ampere-turns from 1 to 1.4-1.6, with increase $K_1$ from 1.5 to 2.5, time delay does not virtually change both at large and at small power.

Taking into account the possible fluctuations of the voltage of battery and change in the load of relay, one should recommend for obtaining minimum triggering time to select the coefficient of the reserve (on ampere-turns) within limits from 1.8 to 2.2.

10-6. Graphoanalytical method of timing of the function of relay.

Up to now there is no simple and sufficient strictly substantiated analytical method of timing of the function of electromagnetic relays. Is explained this to the fact that

the processes, which occur upon the connection/inclusion of relay, are very complex. The complexity of these processes is caused by the nonlinearity of the dependence between exciting current and flow, the nonuniformity of flow distribution according to section and length of magnetic circuit, as a result of eddy-current effect and scattering, and the nonuniformity of the motion of armature during the function of relay.

The given above simplified analytical methods of timing of contact/start and motion of armature are sufficiently complex, they require much time and are not characterized by sufficient accuracy, since they are based on a whole series of assumptions. Therefore use these formulas one should only for tentative calculations, during the development of the new types of relay or when there is no possibility to obtain experimental materials.

For determining triggering time of the standard relays, produced by industry, is considerably more precise and more convenient the graphoanalytical calculation method, proposed by author.

The time delay in general form it is possible to express by following formula [10-20]:

$$t_{cp} = t_{\tau p} + t_{дв} = \tau \ln \frac{AW}{AW - AW_c} + $$
$$+ t_в + t_{дв} \approx \tau \ln \frac{AW}{AW - AW_д}, \quad (10\text{-}29)$$

where $AW_д$ are dynamic ampere-turns of the function of relay, the value of which depends on the time constant $\tau$, of the steady ampere-turns, construction of relay, mechanical load of armature and its moment of inertia.

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In the case of the absence of supplementary resistor/resistance, time constant

$$\tau = \frac{L}{R} = \frac{K_0}{C}.$$

Windieg impedance of relay depending on the size/dimensions of winding space and turn number is expressed by formula (6-11):

$$R = \frac{\pi\rho}{lhk_з}(D_0 + h)w^2 = Cw^2.$$

With the assigned turn number and datum of the construction of resistor coil, of winding decreases with an

increase in altitude of winding/coil and duty factor. The small value of winding impedance $R_m$ in this case can be obtained (of course, only theoretically) with complete filling of entire winding space of coil ($h = h_m$) with red copper rectangular wire with insulation of negligibly small thickness ($k_3$ = 1):

$$R_m = \frac{\pi\rho}{lh_m}(D_0 + h_m)w^2 = C_m w^2,$$

where $h_m$ is a nominal altitude of winding and

$C_m$ - a minimum value of equivalent resistance of one turn in ohms.

With filling of entire winding space of the coil

$$C_m = Ck_3.$$

The maximum value of time constant for this type of relay will be, obviously, equally to:

$$\tau_{\text{макс}} = \frac{L}{R_m} = \frac{K_0}{C_m}.$$

Let us designate the ratio of the maximum value of time constant for this type of relay $\tau_{\text{макс}}$ to the actual constant value of time by m; we will obtain:

$$m = \frac{\tau_{\text{макс}}}{\tau} = \frac{K_0}{\tau C_m}. \qquad (10-30)$$

In the absence of the series-connected resistor/resistance and smallest winding impedance of relay $r_{\text{доб}}$ the value of coefficient m will be also equal to unity (m = 1).

The real winding of relay will always resistive more $R_m$ and the greater, than less filled winding space and is more the thickness of insulation of wire. Consequently, the incomplete use of winding space of coil of equivalently to the connection/inclusion supplementary resistor/resistance $r_d'$ consecutively with the winding of the relay:

$$r_d' = R - R_m, \tag{10-31}$$

where R is actual winding impedance of our relay.

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On the basis of equation (10-30) it is possible formula for the time constant of relay circuit to rewrite as follows:

$$\tau = \frac{K_0}{C_m m}. \tag{10-30a}$$

Substituting in (10-29) for the time delay instead of τ its value, we will obtain:

$$t_{cp} = \frac{K_0}{C_m m} \ln \frac{AW}{AW - AW_\pi} = \frac{K_0}{C_m m} \ln \frac{K_\pi}{K_\pi - 1}. \tag{10-32}$$

Thus, the time delay is the function of value $K_0$, of coefficient m and of the safety factor with respect to the dynamic ampere-turns of function $K_{\text{д}}$.

Value $K_0$ depends on clearance and the magnetizing ampere-turns. Dynamic ampere-turns are complex function of the time constant, value of the steady ampere-turns, mechanical load and moment of the inertia of the armature of relay.

The determination of these values is difficult; therefore the curves of the time delay, obtained experimentally, must be constructed depending on the coefficient of reserve $K_1$ (with respect to the static ampere-turns of function) and the value of coefficient m which do not depend on the course of armature, load of relay and ampere-turns.

Such curved for different types relays are given in Fig. 10-11, 10-12, ..., 10-29.

The ampere-turns of the function of relay, undertaken from certificate, usually maintain narrower certain stock (on certificate) whose value can oscillate within limits from 1.1 to 1.3, on the average 1.2. Therefore for timing of the function of relay, it is necessary to determine the actual real coefficient of the reserve on ampere-turns which on the average is equal to:

$$K_s \approx \frac{aW}{0.8AW} \qquad (10\text{-}33).$$

a) Local circuit.

In the case of the inclusion of relay into local circuit (it is direct to battery clips), the value of coefficient m will be equal to:

$$m = \frac{K_0}{C_m r} = \frac{K_0 R}{C_m L} = \frac{R}{C_m w^2}. \qquad (10\text{-}34)$$

If the winding of relay fills whole winding space of coil, then $C_m = Ck_3$ and

$$m = \frac{R}{C_m w^2} = \frac{Cw^2}{Ck_3 w^2} = \frac{1}{k_3}.$$

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However, virtually filling of the winding space of coils almost always differs from 100o/o; therefore for value determination of coefficient m, one should use formula (10-34).

b) The series connection of effective resistance.

Majority compound circuits easily it can be converted relative to the winding of relay into simple forward circuit.

The time constant of relay circuit, connected in series with effective resistance $r_d$, is equal to:

$$\tau = \frac{L}{R + r_d} = \frac{K_0 w^2}{R + r_d}. \quad (10\text{-}35)$$

Substituting in expression (10-30) instead of $\tau$ its value, we will obtain formula for the computation of coefficient of m in the case of the series connection of effective resistance in relay circuit:

$$m = \frac{K_0 (R + r_d)}{C_m K_0 w^2} = \frac{R + r_d}{C_m w^2}. \quad (10\text{-}36)$$

Let us multiply numerator and the denominator of expression (10-36) on $I^2 = I_c^2 K_1^2$; we will obtain:

$$m = \frac{I^2 (R + r_d)}{C_m w^2 I_c^2 K_1^2} = \frac{P}{C \cdot AW_c^2 k_3 K_1^2} = \frac{1}{k_3 K_1^2} \cdot \frac{P}{P_c}, \quad (10\text{-}36a)$$

where P - the power, expended in relay circuit, and

$P_c$ - the power of the function of relay.

Thus, value m is the safety factor according to power, multiplied by factor $1/k_3K^2{}_1$.

With dual reserve on ampere-turns and $k_3$ = 0.6

$$m = 0{,}417\frac{P}{P_c}.$$

c) The series connection of inductance and effective resistance.

Upon connection/inclusion consecutively with the winding of the relay of inductance $L_d$ and of effective resistance $R_d$ the time constant is equal to:

$$\tau = \frac{L + L_d}{R + R_d} = \frac{Kw^2 + L_d}{R + R_d}. \qquad (10\text{-}37)$$

Substituting in (10-30) instead of $\tau$ its value from equation (10-37), we will obtain for value determination of coefficient m upon the series connection of inductance and effective resistance into relay circuit:

$$m = \frac{K_0(R + R_d)}{C_m(K_0w^2 + L_d)} = \frac{R + R_d}{C_m\left(w^2 + \frac{L_d}{K_0}\right)}. \qquad (10\text{-}38)$$

Set/assuming in equation (10-38) inductance $L_d = 0$, we obtain formula (10-36) for the case of the series-connected effective resistance. If we include/connect consecutively with the winding of relay the inductance, which has the same parameters as relay, then we will obtain:

$$m = \frac{R+R}{C_m\left(w^2 + \frac{K_0 w^2}{K_0}\right)} = \frac{R}{C_m w^2},$$

i.e. in this case the value of coefficient m does not change.

The value of inductance L is assigned, value $K_0$ with this clearance and the assigned ampere-turns we determine by formula (4-50) or we find through experimental curve for the different types of the relays, given in the fourth chapter.

d) Effect of active shunt.

If in parallel to the winding of relay included effective resistance $r_m$ (shunt) and consecutively with battery (in common circuit) is introduced resistor/resistance $r_d$, then time constant is expressed by the following formula:

$$\tau = \frac{L}{R} \cdot \frac{1 + \frac{r_d}{r_m}}{1 + \frac{r_d}{r_m} + \frac{r_d}{R}}, \qquad (10\text{-}39)$$

where L and R - inductance and winding impedance of relay.

Substituting in (10-30) instead of $\tau$ its value, we will obtain formula for determining the coefficient of m in the work of relay in the compound circuit:

$$m=\frac{K_0}{C_m}\cdot\frac{C}{K_0}\frac{\left(1+\frac{r_d}{r_m}+\frac{r_d}{R}\right)}{1+\frac{r_d}{r_m}}=\frac{r_d+R\left(1+\frac{r_d}{r_m}\right)}{C_m w^2\left(1+\frac{r_d}{r_m}\right)}. \quad (10\text{-}40)$$

In the particular case when $r_d=r_m$, the value of coefficient m is equal to:

$$m=\frac{r_d+2R}{2C_m w^2}=\frac{R+\frac{r_d}{2}}{C_m w^2}. \quad (10\text{-}41)$$

In the absence of shunt or series-connected resistor/resistance ($r_d=\infty$ or $r_d=0$) we will obtain given above formula (10-36) for simple series connection. For determining the safety factor on ampere-turns $K_1$, it is necessary to find the value of coil current of relay with the aid of the Ohm's laws and Kirchhoff.

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e) Effect of quadrature winding.

The time constant of the growth/build-up of the resulting magnetic flux of relay in the presence of second quadrature winding and supplementary resistor/resistance $r_d$ in the circuit of the first winding is equal to:

$$\tau = \frac{L_1}{R_1 + r_d} + \frac{L_2}{R_2}, \qquad (10\text{-}42)$$

where $L_2$ and $R_2$ - inductance and the effective resistance of second quadrature winding.

Replacing $L_1$ and $L_2$ by their values, we will obtain:

$$\tau = \frac{K_0 w_1^2}{R_1 + r_d} + \frac{K_0 w_2^2}{C_2 w_2^2} = \frac{K_0}{R_1 + r_d}\left(w_1^2 + \frac{R_1 + r_d}{R_2} w_2^2\right).$$

Substituting in expression (10-37) instead of $\tau$ its value from last/latter equality, we obtain formula for determining the coefficient of $m$ in the presence of second quadrature winding in the case of the even distribution of both windings along the length of the core:

$$m = \frac{K_0}{C_m \frac{K_0}{R_1 + r_d}\left(w_1^2 + \frac{R_1 + r_d}{R_2} w_2^2\right)} = \frac{R_1 + r_d}{C_m\left(w_1^2 + \frac{R_1 + r_d}{R_2} w_2^2\right)}. \qquad (10\text{-}43)$$

If in parallel to the first winding included effective resistance $r_m$ (shunt), then the value of coefficient m can be determined by the following formula:

$$m=\frac{1}{C_m\left[\frac{w_1^2}{R_1}\left(\frac{1+\frac{r_d}{r_m}}{1+\frac{r_d}{r_m}+\frac{r_d}{R_1}}\right)+\frac{w_2^2}{R_2}\right]}. \quad (10\text{-}43a)$$

If quadrature winding is absent ($w_2 = 0$ or $R_2 = \infty$), then of (10-43) we obtain formula (10-36) for the case of the series connection of effective resistance.

For timing of the function of time-lags relay, working in compound circuits, it is possible to use all given above formulas, if we for each type of time-lag relay remove/take experimentally the curved dependences $t_{cp}$ on m at the different $K_1$. The value of coefficient $C_m$ for time-lag relay is determined by the size/dimensions of the useful winding space, occupied only by inducing winding (space, occupied by quadrature winding is not considered).

During the nonuniform distribution of both windings along the length of core, changes magnetic flux distribution at the moment of function, and therefore in this case the time delay cannot be designed from formula (10-43).

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f) Calculation of relay for assigned triggering time.

The given below curves it is possible to also use for the calculation of relay for any assigned time of function. From these curves it follows that one and the same triggering time can be obtained with the different safety factors on ampere-turns, if we select the appropriate value of coefficient of m.

Therefore during the calculation of relay for the assigned triggering time, it is necessary to be given the value of the coefficient of reserve $K_1$. Above we narrower established that for achievement of the maximum speed of function the value of the safety factor on ampere-turns $K_1$ must be within the limits approximately from 1.8 to 2.2.

Being given the value of the safety factor within these limits, we find through curves the value of

coefficient of m which it must have a circuit of our relay in order to ensure necessary speed of response.

In the case of the series connection of inductance and resistor/resistance, the value of coefficient m according to formula (10-38) is equal to:

$$m = \frac{R + r_d}{C_m\left(w^2 + \frac{L_d}{K_0}\right)}.$$

On the other hand,

$$AW = 0{,}8K_1 AW_c = \frac{Uw}{R + r_d},$$

whence

$$R + r_d = \frac{Uw}{0{,}8K_1 AW_c}. \qquad (10\text{-}44)$$

Substituting in formula for m instead of $(R + r_d)$ its value from last/latter expression, we obtain:

$$m = \frac{Uw}{0{,}8K_1 AW_c C_m\left(w^2 + \frac{L_d}{K_0}\right)}$$

or

$$mC_m 0{,}8K_1 AW_c w^2 - Uw + mC_m 0{,}8K_1 AW_c \frac{L_d}{K_0} = 0,$$

whence we find formula for determining the turn number of the winding of relay during its calculation for assigned triggering time:

$$w = \frac{U}{1{,}6mC_m K_1 AW_c} \pm \sqrt{\frac{U^2}{2{,}56m^2 C_m^2 K_1^2 AW_c^2} - \frac{L_d^2}{K_0}}. \qquad (10\text{-}45)$$

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If consecutively from relay is included only effective resistance ($L_d = 0$), then formula for a turn number will take the following form:

$$w = \frac{U}{0{,}8mC_m K_1 AW_c}. \qquad (10\text{-}46)$$

The value of the supplementary resistor/resistance which must be include/connected consecutively with the winding of relay in order to obtain preset time, we find from equation (10-44), substituting instead of w its value:

$$r_d = \frac{Uw}{0{,}8K_1 AW_c} - R, \qquad (10\text{-}47)$$

where R - winding impedance of relay.

Supplementary resistor/resistance $r_d$ can be wound on the coil of relay, if the total power, consumed in this case, will not exceed the maximum thermal load of relay.

If relay is shunted by effective resistance $r_m$, then according to 810-40) the value of coefficient m will be equal to:

$$m=\frac{R+r_d\left(1+\frac{R}{r_{\text{ш}}}\right)}{C_m w^2\left(1+\frac{r_d}{r_{\text{ш}}}\right)}=\frac{Rr_{\text{ш}}+r_d(r_{\text{ш}}+R)}{r_{\text{ш}}C_m w^2\left(1+\frac{r_d}{r_{\text{ш}}}\right)}.$$

On the other hand, according to (7-12) we have:

$$AW=0{,}8K_1AW_c=\frac{Uwr_{\text{ш}}}{r_d(r_{\text{ш}}+R)+Rr_{\text{ш}}},$$

whence

$$\frac{Rr_{\text{ш}}+r_d(r_{\text{ш}}+R)}{r_{\text{ш}}}=\frac{Uw}{0{,}8K_1AW_c}. \qquad (10\text{-}48)$$

Substituting (10-48) into expression for m, we obtain:

$$m=\frac{U}{0{,}8K_1AW_cC_m w\left(1+\frac{r_d}{r_{\text{ш}}}\right)},$$

whence we find formula for determining the turn number of the winding of the relay:

$$w=\frac{U}{0{,}8C_m mK_1AW_c\left(1+\frac{r_d}{r_{\text{ш}}}\right)}, \qquad (10\text{-}49)$$

where $r_d$ is the supplementary resistor/resistance, connected in series with battery in common circuit.

Winding impedance of relay we find from equation (10-48); we have:

$$R=\frac{(Uw-K_1AW_cr_d)\,r_{\text{ш}}}{0{,}8K_1AW_c(r_{\text{ш}}+r_d)}. \qquad (10\text{-}48a)$$

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10-7. Curved for timing of the function of standard relays.

For timing of function by graphoanalytical method it is necessary previously to remove/take experimentally the family of curves of the dependence of the time delay on the value of coefficient m with the different safety factors on ampere-turns, moreover for circuit closing contacts and interrupting relay it is necessary to construct separate family of curves, since triggering times of these contacts are different. The contact system of relay of the type RKN is comprised of four fundamental cell/elements: No 1 is closing/shorting, No 2 - interrupting, No 3 - switching with interrupting before closing/shorting and No 4 - switching with closing/shorting before interrupting. These relays can be easily controlled in such a way that all circuit closing contacts of different cell/elements would be closed virtually simultaneously and all circuit opening contacts of these cell/elements were broken also

approximately simultaneously. Therefore independent of quantity and type of contact cell/elements for timing of the function of relay of the type RKN sufficient to have two families of curves: one for circuit closing contacts and another for circuit opening contacts.

The contact systems of relay of the type RPN and of type 100 consist of a large quantity of different types of the contact groups, which have different mechanical characteristics. These groups are constructed according to other principles and by no means everything can be controlled in such a way as to obtain approximately simultaneous closing/shorting or interrupting different contacts.

Consequently, the time delay of the type PN (or type 100), loaded by the different types of contact groups, under one and the same margins of safety and other equal conditions - is different. For the precision determination of triggering time of these relays with different loads, it is necessary to have for each type of contact groups separate curves.

For the tentative timing of the function of the different types of the relays, loaded by one group for switching and connected successively with effective resistance, it is possible to use the curves of the dependence of triggering time on power, given in Fig. 1-28b.

a) Relays of the type RPN.

For timing of the function of relay of the type RPN Fig. 10-11 gives the curves of the dependences of triggering time of this relay on the value of coefficient m with different coefficients of reserve on ampere-turns, taken experimentally.

Relay was loaded by one contact group for switching No 03 (u). Adjustment of relay normal; the course of armature 1.1 mm, the thickness of nonmagnetic antistick strip 0.3 mm.

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By solid lines are constructed curves for circuit closing contacts, and broken - for circuit opening contacts.

The curves of the dependences of triggering time of this relay on the safety factor with a constant value of coefficient m = 1.9 are given on Fig. 10-12.

Value $C_m$ for a normal relay of the type RPN is equal to:

$$C_m = \frac{\pi\rho \cdot 10^{-8}}{lh}(D_0 + h) = \\ = \frac{\pi \cdot 0{,}0175 \cdot 10^{-6}}{50 \cdot 6{,}6}\left[\frac{2}{\pi}(4{,}3 + 10{,}8) + 6{,}6\right] = 2{,}7 \cdot 10^{-9} \text{ ohm.}$$

With an increase in the course of armature from 1.1 to 1.5 mm, the time delay increases by 15-18o/o.

To Fig. 10-13, are given the curves of the dependences of the time delay of the type RPN on the value of coefficient m with dual reserve on ampere-turns, taken with

three different loads - 5, 10 and 15 contact springs (1, 2 and 3 groups No 102). Value of the course of the armature of relay 1.5 mm, the thickness of nonmagnetic antistick strip 0.3 mm.

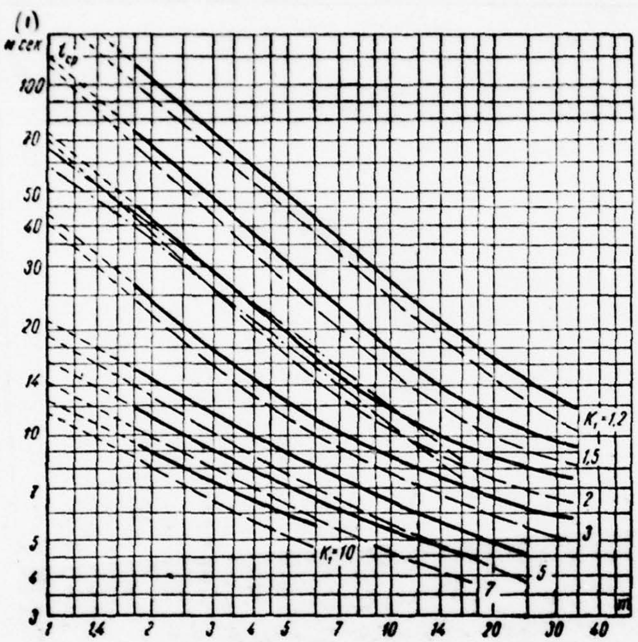


Fig. 10-11. Curves of the time delay of the type RPN ($C_m = 2{,}7 \cdot 10^{-6}$ ohm).

Key: (1). m s.

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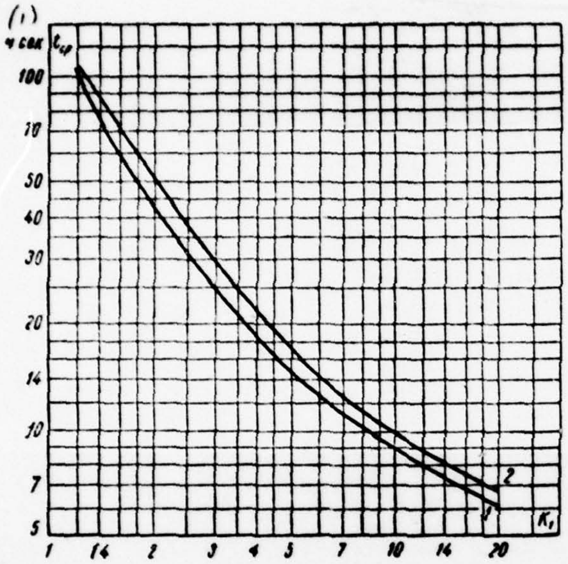


Fig. 10-12. Curved of the dependences of the time delay of the type RPN on the safety factor. 1 - normal relay; 2 - time-lag relay.

Key: (1). m s.

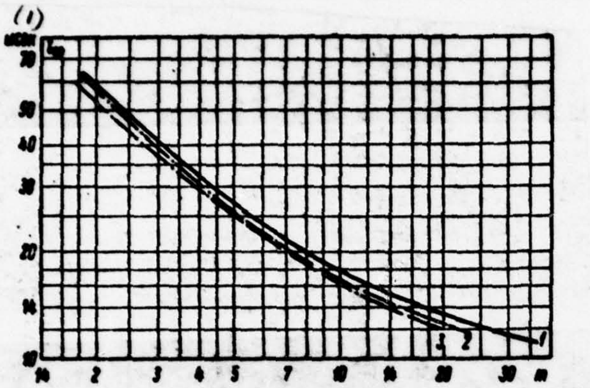

Fig. 10-13. Comparative curves of the time delay of the type RPN. 1 - load of 5 springs; 2 - load of 10 springs; 3 - load of 15 springs.

Key: (1). m s.

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From these curves it follows that the time delay with uniform contact load does not in practice depend on the load of relay (quantity of contact springs); it depends only on the value of the safety factor on ampere-turns and the value of coefficient of m. The small deviations of the time delay with different loads are explained by an

inaccuracy in adjustment and by errors of measurement. An increase in the load of relay with the constant value of the applied voltage and the constant/invariable resistor/resistance of circuit, of course, will lead to an increase in triggering time due to a decrease in value $K_1$.

To Fig. 10-14, are given the curves of the dependences of the time delay of the type RPN, loaded by the different types of contact groups on the value of coefficient m with double reserve on ampere-turns.

Time-lag relay of the type RPN.

Time-lags relay of the type RPN depending on the necessary degree of the time dilation of work have on core (under winding) quadrature winding of 2, 4 or 6 layers of bare copper (tinplated) wire as diameter 0.5 mm. The height/altitude of quadrature winding $h_K$ is respectively equal to 1.2 or to 3 mm.

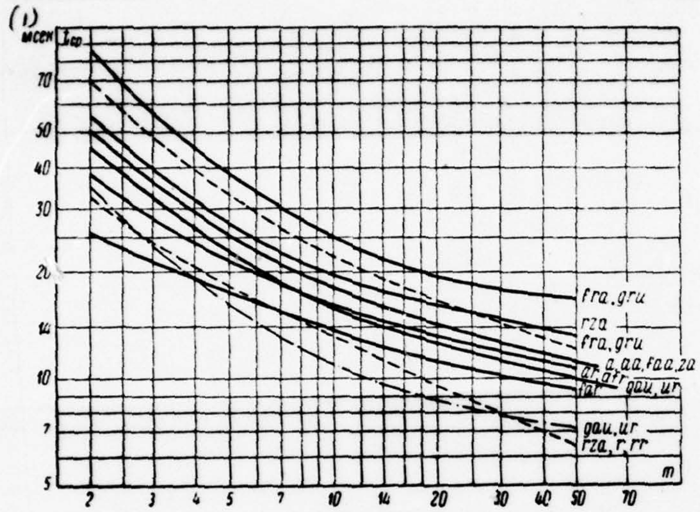


**Fig. 10-14. Curved of the time** delay of the type RPN, loaded by the different types of contact groups with $K_1$ = 2; solid lines are circuit closing contacts; broken - the breaking contact.

Key: (1). m s.

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To Fig. 10-15, are given the curves of the dependences of triggering time of time-lag relay of **the type** RPN with the height/altitude of quadrature winding $h_к = 3$ mm on the

value of coefficient m with the different safety factors on ampere-turns. Relay loaded by one contact group to switching No 03, the course of armature 1.1 mm the thickness of nonmagnetic antistick strip 0.3 mm.

Value $C_m$ for time-lag relay is calculated from value free winding of space:

$$C_m = \frac{\pi \cdot 1{,}75 \cdot 10^{-8}}{50 \cdot 3{,}6 \cdot 10^{-3}} (15{,}6 + 3{,}6) = 5{,}86 \cdot 10^{-6} \text{ ohm.}$$

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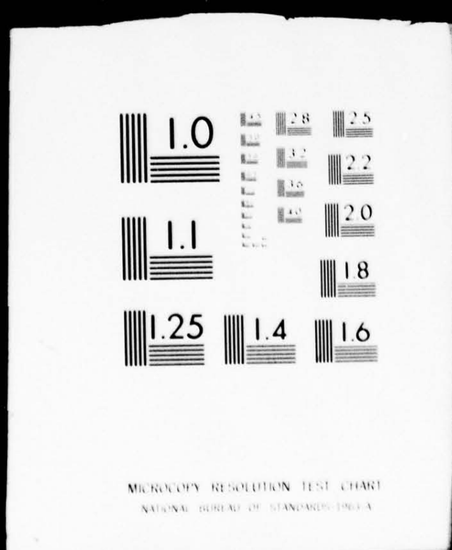

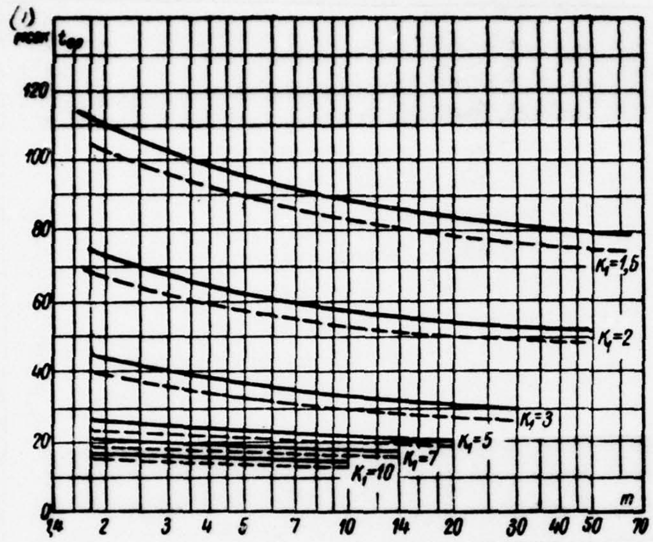


Fig. 10-15. Curved of triggering time of time-lag relay of the type RPN with $h_K = 3$ mm.

Key: (1). m s.

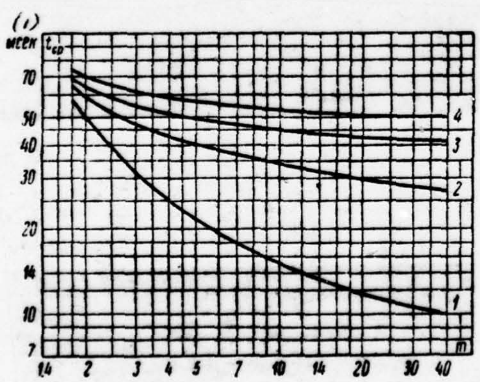


Fig. 10-16. Comparative curves of the time delay of the type RPN with $K_1$ = 2. 1 - normal relay; 2 - time-lag

relay, $h_K = 1$ mm; 3 - Delay relay $h_K = 2$ mm, 4 - time-lag relay $h_K = 3$ mm.

Key: (1). m s.

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Comparing these curves with Fig. 10-11, we are convinced of the fact that triggering time for time-lag relay at low values of coefficient of m differs little from triggering time of the normal unretarded relays. But with an increase in coefficient m triggering time of time-lags relay is little affected, while for a normal relay it strongly decreases.

The curves of the dependences of triggering time of normal (1) and the deferred-action (2, 3, 4) relays of the type RPN on the value of coefficient m and of the safety factor on ampere-turns are shown to Figs. 10-16 and 10-12.

b) relays of the type RKN.

For timing of the function of normal relays of the type RKN for Fig. 10-17, are given the curves of the dependences of triggering time of these relays on the value of coefficient m with the different safety factors on ampere-turns.

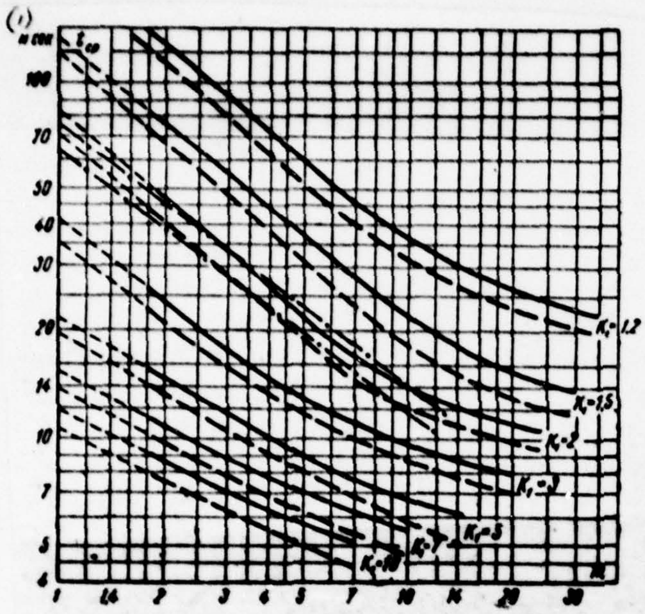


Fig. 10-17. Curved of triggering time of a normal relay of the type RKN (front/leading jaw of coil is copper; $C_m = 2,25 \cdot 10^{-6}$ ohm); solid lines - circuit closing contacts; broken are the breaking contact.

Key: (1). m s.

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The curves of the dependences of the time delay of the type RKN on the safety factor with a constant value

of coefficient m are given on Fig. 10-18; these curves, actually, characterize by themselves the dependence of the time delay on the applied voltage, other conditions being equal.

The front jaw of the coil of relay of the type RKN for a decrease in the vibration of armature is manufactured of red copper; however, copper jaw gears down of function; therefore for high-speed relays both jaws are manufactured from getinax.

Test (stop) relays of the type RKN for an increase in speed of response have a core without the pole piece. Both jaws of the coil of this relay are manufactured from getinax.

To Fig. 10-19, are given the curves of the dependences of triggering time of breakdown of relay of the type RKN on the value of coefficient m with the dual safety factor. For a comparison to Fig. 10-19, are shown additionally two curves for relay with the pole piece: one for a normal relay with the front/leading jaw of coil of copper (1), another for relay with getinax jaw (2). Relays were loaded by two groups for switching (No 3); the course of armature is equal to 0.8 mm, the height/altitude of the plug of loosening 0.3 mm.

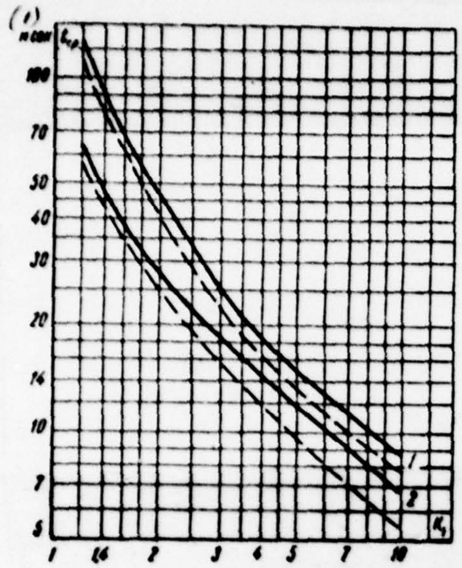

Fig. 10-18. Curved of the dependences of the time delay of the type RKN on the safety factor on ampere-turns; solid lines are circuit closing contacts; broken - the breaking contact. 1 - normal relay (jaw copper); 2 - test relay.

Key: (1). m s.

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From these curves it follows that triggering time of the test relays, which do not have the pole piece, is considerably shorter than triggering time of normal relays

of the type RKN. At low values of coefficient of m, the time delay of the type RKN does not depend on the material of the front/leading jaw of coil; at large values of m triggering time of normal relay with front/leading jaw from copper of the more time delay with jaw from getinax.

The greatest useful height/altitude of the winding of relay of the type RKN when of calculation $C_m$ was accepted equal to 6.7 mm:

$$C_m = \frac{\pi \cdot 1{,}75 \cdot 10^{-8}}{59{,}1 \cdot 6{,}7 \cdot 10^{-8}} (9{,}5 + 6{,}7) = 2{,}25 \cdot 10^{6} \text{ ohm.}$$

Time-lag relay of the type RKN.

Depending on the location of red copper plug along the length of the core of relay of the type RKN, as is known, they are divided into those who were retarded during function and those who were retarded with release/tempering.

The relay, retarded for function, has a plug of the

end/lead of the core (against armature); in the relay, delayed for release/tempering, the plug is arrange/located at heel. The relay, retarded for function, is, of course, retarded also for release/tempering.

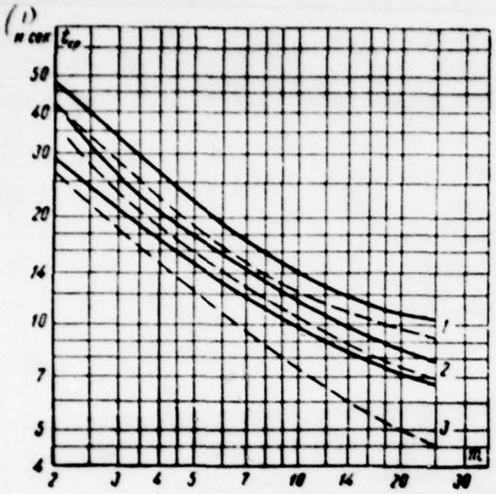


Fig. 10-19. Curved of the time delay of the type RKN with $K_1$ = 2; solid lines are circuit closing contacts; broken - the breaking contact. 1 - normal relay (jaw copper); 2 - relay with front/leading jaw out of getinax; 3 - test relay.

Key: (1). m s.

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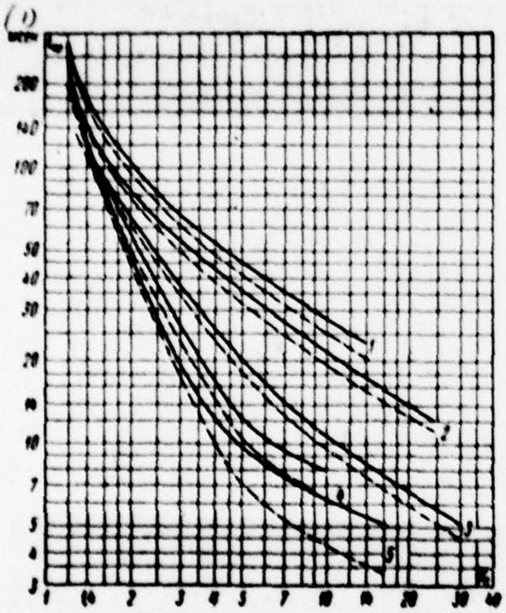


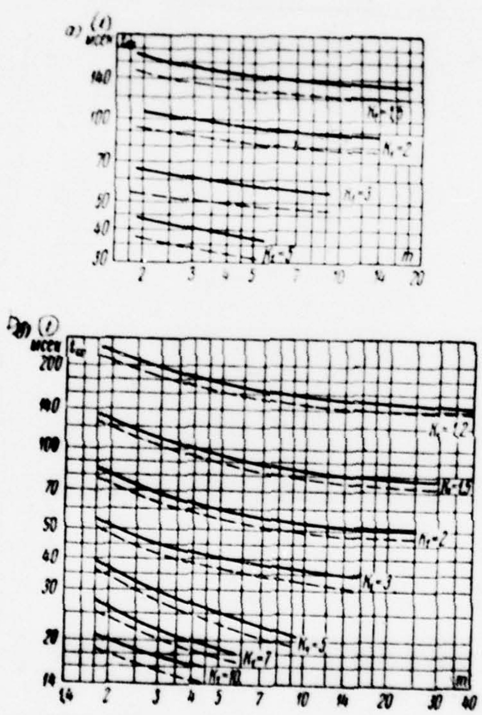
Fig. 10-20.

Fig. 10-20. Curved of triggering time of time-lags relay of the type RKN. 1 - retarded on functioning (plug 38 mm); 2 - the same (plug 25.5 mm); 3 - normal relay (jaw copper); 4 - retarded for release/tempering (plug 38 mm); 5 - the same (plug 25.5 mm).

Key: (1). m s.

Fig. 10-21. Curved of triggering time of the deferred-action during function relays of the type RKN: a) the length of plug 38 mm; b) the length of plug 25.5 mm.

Key: (1). m s.



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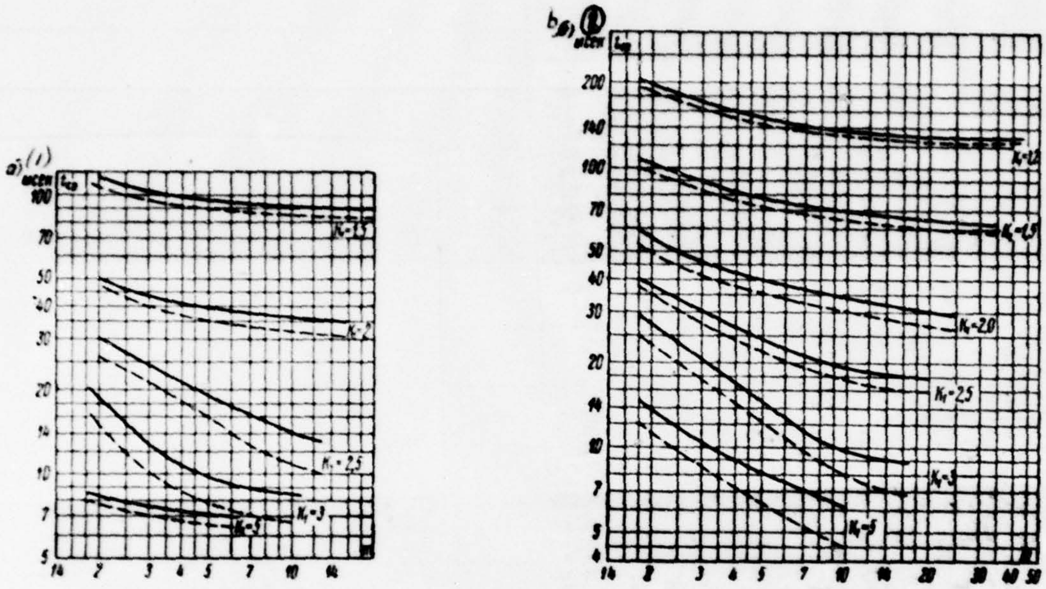

Fig. 10-22. Curved of triggering time of the deferred-action for release/tempering relays of the type RKN: a) the length of plug 38 mm; b) the length of plug 25.5 mm.

Key: (1). m s.

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The degree of the time dilation of the work of relay is determined by the length of plug. Plugs are applied three size/dimensions: by length 38 mm, 25.5 mm even 12.8

mm. To Fig. 10-20, are given the curves of the dependences of the time delay of the type RKN, delayed for function and release/tempering, on the safety factor on ampere-turns with the plugs of different length. These curves are obtained with the filling of entire winding space of coils with red copper wire with enamel insulation (d = 0.10-0.14 mm) and the connection/inclusion of relay to "pure/clean" battery, which corresponds to the value of coefficient of m approximately 1.74.

From Fig. 10-20, it follows that upon connection/inclusion for "Bath's pure/clean" to yard the time delay, retarded for release/tempering, even is less than for normal, not time-lag relay. For the calculation of relays of the type RKN, retarded for function and release/tempering, at the different values of coefficient of m for Figs. 10-21 and 10-22 are given the curves of the dependences of triggering time of these relays on the value of coefficients m and $K_1$.

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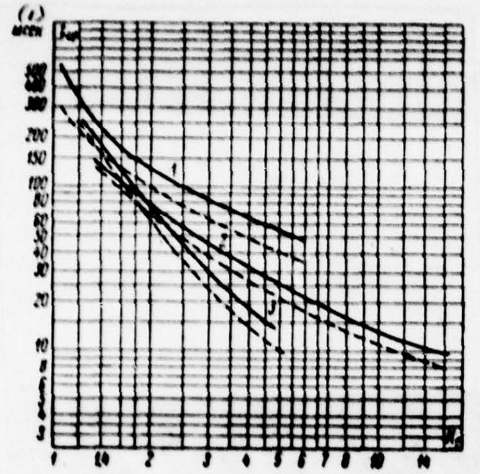

Fig. 10-23. Curved of triggering time of time-lags relay of the type RKN with large load (14 springs): solid lines is the circuit closing contacts; broken - the breaking contact. 1 - retarded for function (plug 38 mm); 2 - normal relay (jaw copper); 3 - retarded for release/tempering (plug 38 mm).

Key: (1). m s.

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Comparing these curves with Fig. 10-17, we are convinced of

the fact that the series connection of resistor/resistance comparatively barely affects triggering time of time-lags relay, while in normal relays this dependence is very strongly expressed. Therefore speed advantage of the function of the deferred-action for release/tempering relays of the type RKN rapidly disappears upon the connection/inclusion of supplementary resistor/resistance.

All these curves were taken with the load of relay by two groups of switching No 3.

If time-lag relay is loaded with a large quantity of springs, then during the especially careful adjustment of the groups when all circuit closing contacts and interrupting respectively are closed or are broken simultaneously, it is possible to obtain virtually the same triggering times as for the relay, loaded by one group No 3.

During nonsimultaneous closing/shorting and interrupting of the corresponding contacts of the different groups of relay, the contact time of interrupting will strongly differ from the contact time of closing/shorting. For the illustration of this phenomenon to Fig. 10-23, are given

the curves of triggering time of time-lags relay of the type RKN, loaded by fourteen by springs and controlled inaccurately.

In operation the heterogeneity of the closing/shorting of different contacts can occur; therefore for timing of the function of the strongly loaded relays, one should use last/latter curves.

During the computation of coefficient $C_m$ for time-lag relay, is accepted only useful winding space without taking into account of place, occupied by the plug. For time-lag relay with plug length 38 mm value $C_m = 6{,}55 \cdot 10^{-6}$ ohm, for relay with plug 25.5 mm coefficient $C_m = 4{,}05 \cdot 10^{-6}$ ohm.

c) relays of the type RES14.

To Fig. 10-24, are given the curves of the dependences of triggering time on the value of coefficient m at different values $K_1$ for normal and time-lag relay of the type RES14, loaded four by stud switches. By dotted line are shown curves for the breaking contact.

The value of coefficient $C_m$ for a normal relay is equal to $C_m = 2{,}62 \cdot 10^{-6}$ ohm and for that which was retarded with $h_к = 3$ mm the coefficient $C_m = 5{,}6 \cdot 10^{-6}$ ohm.

The curves of the dependences of triggering time of these relays on the safety factor with m ≈ 1.8 are given to Fig. 10-25.

d) the relays of different types.

To Fig. 10-26, are shown the curves of the dependences of triggering time on the value of coefficient m with dual reserve on spill current ($K_1$ = 2) for the relay of the types: RKMP, RKM-1, RES8, RMU, RS-52, TKYe 52PD, TKYe 21PD, RES22, RES6, RES9, RES10 and RES15. Dotted line designated curves for the breaking contact.

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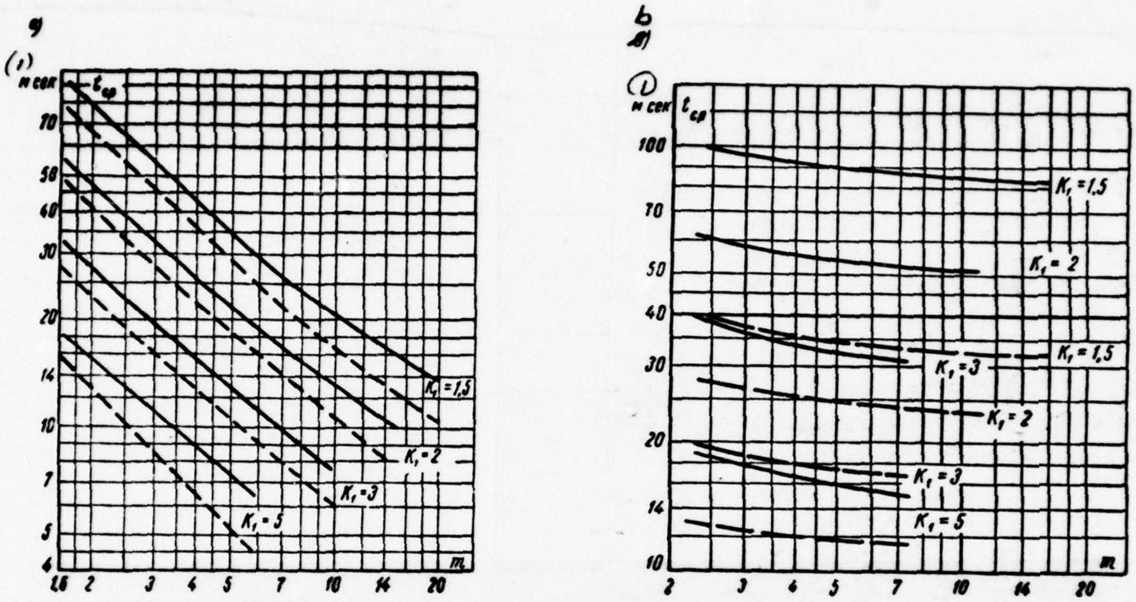


Fig. 10-24. Curved of the time delay of the type RES14: a) normal ($C_m = 2{,}62 \cdot 10^{-6}$ ohm); b) retarded ($h_к = 3{,}0$ мм; $C_m = 5{,}6 \cdot 10^{-6}$ ohm).

Key: (1). m s.

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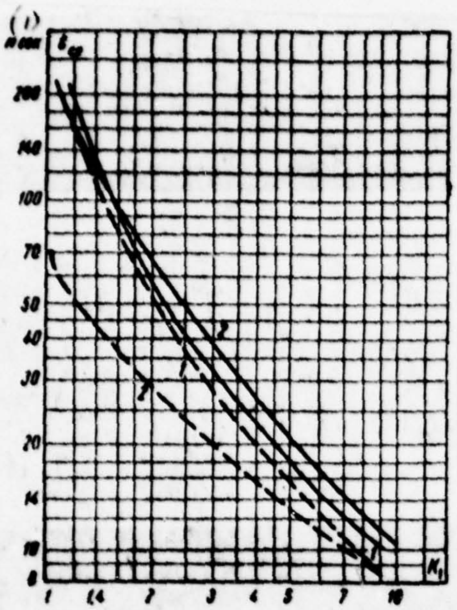

Fig. 10-25.

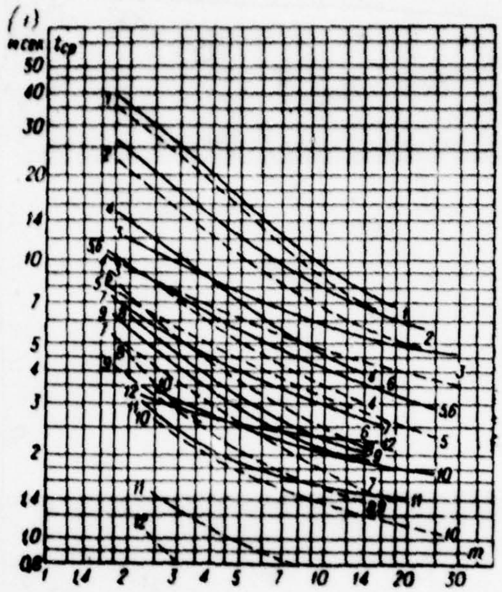

Fig. 10-26.

Fig. 10-25. Curved of the dependences of the time delay of the type RES14 on the safety factor. 1 - normal relay (m = 1.8); 2 - time-lag relay ($h_{H}$ = 3 мм).

Key: (1). m s.

Fig. 10-26. Curved of triggering time of the different types of relay with $K_1$ = 2. 1 - type RKMP; 2 - type RKM-1; 3 - type RES8; 4 - type RMU; 5 - type RS-52; 6 - type TKYe52PD; 7 - type TKYe21PD; 8 - type RES22; 9 -

type RES6; 10 - type RES9; 11 - type RES10; 12 - type RES15.

Key: (1). m s.

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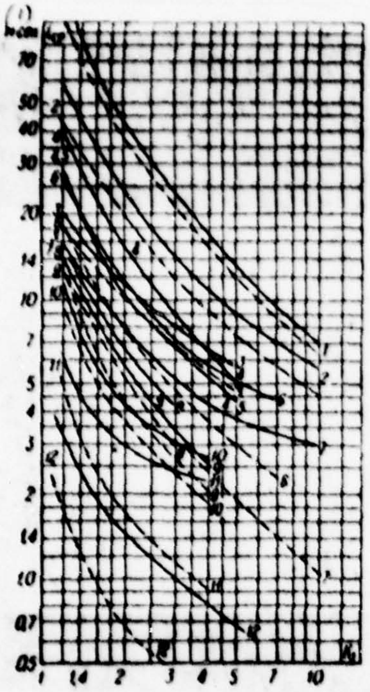

Fig. 10-27.

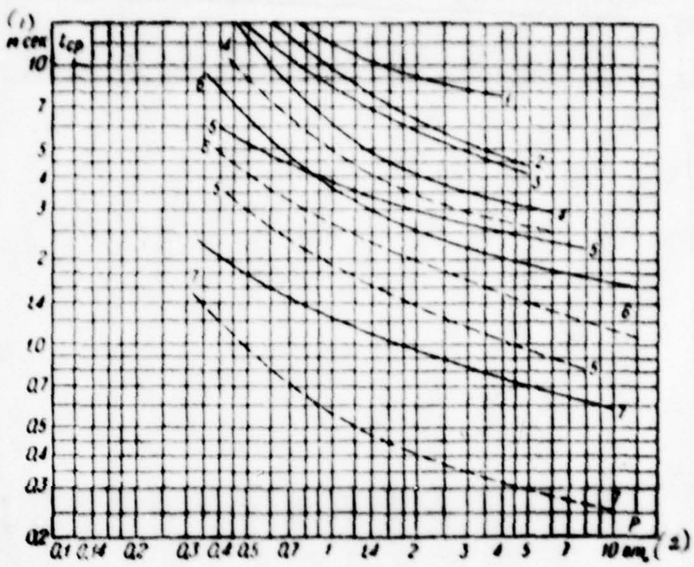

Fig. 10-28.

Fig. 10-27. Curved of triggering time of the different types of relay with m ≈ 1.8. 1 - type RKMP; 2 - type RKM-1; 3 - type RES8; 4 - type RMU; 5 - type RS-52; 6 - type TKYe52PD; 7 - type TKYe21PD; 8 - type RES22; 9 - type RES6; 10 - type RES9; 11 - type RES10, 12 - type RES15.

Key: (1). m s.

Fig. 10-28. Curved of the dependences of the time delay on the amount of power input at load by one stud switch. 1 - type RKN; 2 - type RMU; 3 - type RKM-1; 4 - type RES6; 5 - type RES10; 6 - type RES9 (with two stud switches); 7 - type RES15.

Key: (1). m s. (2). W.

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Values of coefficients $C_m$ for all types enumerated above of relay are given in table 6-4.

The curves of the dependences of triggering time of these types of relay on the safety factor on spill current with m ≈ 1.8 are given to Fig. 10-27.

For tentative calculations for Figs. 10-28 and 10-29, are given the curves of the dependences of the time delay of types RKN, RMU, RKM-1, RES6, RES10, RES15 and RDCG on the amount of power input at load by one stud switch, and

a relay of the type RES9, loaded by two stud switches. By dotted line are shown curves for the breaking contact.

10-8. Empirical formulas for triggering time.

The graphoanalytical calculation method is simple, but it requires the presence of a large quantity of experimental curves. Therefore let us attempt on the base of experimental curves to obtain empirical formulas for timing of the function of relay.

From Fig. 10-11, it follows that the curves of the dependences of the time delay RPN on the value of coefficient m on logarithmic scale are on considerable section virtually straight lines.

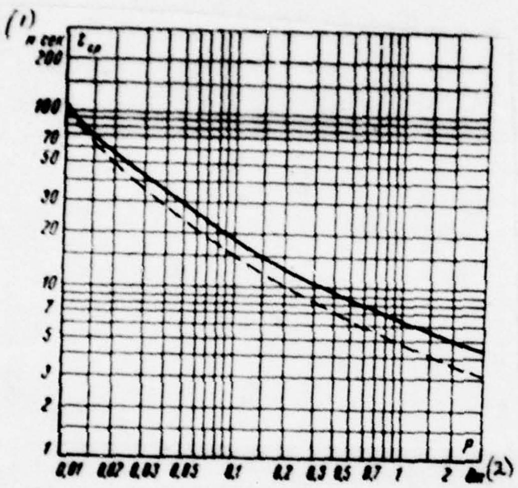


**Fig. 10-29. Curved of the dependences of the time delay of the type RDCG on power** ($P_c = 8{,}4$ **mW**).

Key: (1). m s. (2). W.

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With the dual coefficient of reserve ($K_1 = 2$) the curves of the time delay of the type RPN very differ little from straight lines within the limits of a change in value m approximately from 1.8 to 5.

Consequently, the dependence of time consequently, the

dependence of the time delay on the value of coefficient m on the straight portion of each curve can be approximated by the formula of the following form:

$$t_{cp} = t_{m1} m^{a},$$

where $t_{m1}$ — triggering time which would have relay with m = 1 and this coefficient of reserve and a - the slope tangent of the corresponding straight line to the axis of abscissas (value m = 1 when $h = h_m$ and $k_3$ = 1).

The investigations, carried out by author, showed that during a change in the safety factor within the most frequently encountered limits approximately from 1.5 to 3 value $t_{m1}$ with sufficient for practical calculations accuracy can be expressed by the following equation:

$$t_{m1} = t_{k1} K_1^{-b},$$

where $t_{k1}$ — is equal to value $t_{m1}$, intercept/detached on the axis of ordinates by continuation of the straight portion of curve $t_{m1} = f(K_1)$ and by b - the slope tangent of this section to the axis of abscissas.

Substituting last/latter expression in formula for the time delay, we obtain:

$$t_{cp} = t_{k1} K_1^{-b} m^{-a}. \qquad (10\text{-}50)$$

The value of exponent b of valve type relay varies usually within limits from 1.4 to 1.6.

if we disregard eddy-current effect and time of the motion of armature, then exponent a, according to formula (10-32), must be equal to unity (a = 1). Virtually a approaches unity of the high speed (not retarded) relay with the small safety factors ($K_1$ = 1.5-2). The value of quantity a of valve type normal (not retarded) relay at the safety factors from 1.5 to 3 is found usually within limits approximately from 0.7 to 0.95.

Thus, the time delay of valve type within limits of values $K_1$ from 1.5 to 3 and m from 1.6-1.8 approximately to 5 can be expressed approximation formula:

$$t_{cp} \approx t_{k1} K_1^{-1.5} m^{-0.85}. \qquad (10\text{-}50a)$$

Within the wider measurement ranges of value m approximately from 1.6-1.8 to 10-12 curves of the time delay of valve type approximately can be replaced by straight lines, that have the slope tangent of approximately

0.75 (a = 0.75). Such straight lines for relay of the type RPN with $K_1$ = 2 are shown to Fig. 10-11 by dotted line with points. The deviation of the curves of the time delay from these straight lines during a change in value m from 1.8 to 10 does not exceed 10o/o.

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Consequently, within the limits of changes in coefficient m from 1.6 to 10-12 and the safety factor from 1.5 to 3 time delay of valve type will be approximately equally to:

$$t_{cp} \approx t'_{k1} K_1^{-1.5} m^{-0.75} = \frac{t'_{k1}}{\sqrt{K_1^3 \sqrt{m^3}}}, \qquad (10\text{-}50b)$$

where $t'_{k1}$ — the value $t_{k1}$, obtained with a = 0.75.

For the case of simple series circuit, substituting for m its value from equation (10-36a), we obtain:

$$t_{cp} \approx \frac{t'_{k1} \sqrt{w^3}}{\sqrt{K_1^3 \sqrt{\left(\frac{R + r_d}{C_m}\right)^3}}} = \frac{t'_{k1}}{\sqrt[4]{\left(\frac{P}{k_3 P_c}\right)^3}}. \qquad (10\text{-}50c)$$

Voltage relay, as a rule, is included without supplementary resistor/resistance, and the value of

coefficient m in this case depending on the diameter of wire and height/altitude of winding/coil varies within comparatively small limits, approximately from 1.7 to 2.3.

Set/assuming m = 2, we obtain for hardly the voltage:

$$t_{op} \approx \frac{t'_{h1}}{1{,}68\sqrt{K_1^?}}. \qquad (10\text{-}50d)$$

With dual reserve on the spill current ($K_1$ = 2) and of m = 2, we have:

$$t_{op} \approx 0{,}21 t'_{h1}. \qquad (10\text{-}50e)$$

With large values of coefficient of m (approximately from 10 to 30) and safety factor from 1.5 to 3, value of exponent a of valve type relay is within the limits from 0.4 to 0.6, and the time delay can be expressed simpler approximation formula:

$$t_{op} \approx \frac{t''_{h1}}{\sqrt{mK_1^?}}. \qquad (10\text{-}50f)$$

The value of quantities $t'_{h1}$ and $t''_{h1}$ for any unretarded relay of valve type can be easily found experimentally. For this, is sufficient to measure the time delay at several values of coefficients of m and $K_1$, to determine value $t'_{h1}$ or $t''_{h1}$ from formulas (10-50b) or (10-50f) and to find average from the obtained results.

Tentative value $t'_{h1}$ for any type of relay can be found by the measurement of triggering time of this relay at $K_1 = 2$ and $m = 5$. In this case

$$t'_{h1} \approx 9{,}45 t_{op}.$$

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Values $t'_{h1}$ and $t''_{h1}$ for the different types of relay are given in table 10-1.

10-9. Effect of capacitance/capacity on the time delay.

a) the connection/inclusion of capacitance/capacity in parallel to the winding of relay.

In the case of the presence in the feed circuit of common/general/total supplementary resistor/resistance $r_d$ (Fig. 10-30) the connection/inclusion of capacitance/capacity causes an increase in the time delay. Is explained this to the

fact that at the first torque/moment after connection/inclusion the current goes, mainly, to charge of capacitor, and only with boosting on its terminal/grippers increases the current, passing through the winding of relay.

Table 10-1. Values of quantities $t'_{k_1}$ and $t''_{k_1}$ for the different types of relay.

| (1) Тип реле | (2) Нагрузка | (3) Замыкающие контакты | | (4) Размыкающие контакты | |
|---|---|---|---|---|---|
| | | $t'_{k_1}$, (5) мсек | $t''_{k_1}$, (5) мсек | $t'_{k_1}$, (5) мсек | $t''_{k_1}$, (5) мсек |
| РКН (6) нормальное | п—п | 220 | 133 | 200 | 115 |
| РКН пробное ($d_п = 9$ мм) | п—п | 137 | 87 | 120 | 66 |
| РКМП (7) | ппп—ппп | 166 | 85 | 152 | 74 |
| РКМ-1 | п—з—п | 114 | 71 | 96 | 57 |
| РПН | п—з—п | 191 | 104 | 167 | 90 |
| РЭС14 | п—п—п—п | 217 | 112 | 182 | 91 |
| РЭН17 | зз—пп | 195 | 115 | 154 | 81 |
| МКУ-48 | зз—пп | 87 | 69 | 65 | 48 |
| КДР1 | п—п | 163 | 105 | 126 | 71 |
| РМУ | п—п | 65 | 37 | 48 | 30 |
| РС-13 | ппп—ппп | 56 | 41 | 43 | 31 |
| РС-52 | п—п | 51 | 38 | 38 | 29 |
| РЭС6 | п—п | 28 | 17 | 20 | 16 |

Key: (1). Type of relay. (2). Load. (3). Circuit closing contacts. (4). Breaking contact. (5). ms. (6). normal. (7). test.

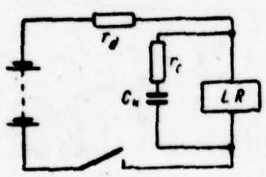


Fig. 10-30. Circuit diagram of capacitance/capacity in parallel to the winding of relay.

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Upon the inclusion of circuit in the case of aperiodic process, the value of the current, passing through the winding of relay, as is known, is expressed by following formula [13-6]:

$$i = \frac{U}{R + r_d}\left[1 - e^{-bt}\left(\mathrm{ch}\,\omega_0 t + \frac{a_0 b - a^2}{a_0 \omega_0}\,\mathrm{sh}\,\omega_0 t\right)\right], \quad (10\text{-}51)$$

where

$$\omega_0 = \sqrt{b^2 - a^2}, \quad a_0 = \frac{1}{r_c C_\kappa}, \quad a^2 = \frac{R + r_d}{(r_d + r_c) L C_\kappa};$$

$$b = \frac{(Rr_d + Rr_c + r_d r_c) C_\kappa + L}{2LC_\kappa (r_d + r_c)}.$$

This equation cannot be solved relative to time.

For simplification in the problem, let us assume that the inductance of relay is small and resistor/resistance $r_c$ is equal to zero.

In this case, set/assuming $L \approx 0$, it is possible to write for the current, passing through the winding of relay upon connection/inclusion, the following expression:

$$i = \frac{U}{R + r_d}\left(1 - e^{-\frac{t}{\tau_c}}\right) = I\left(1 - e^{-\frac{t}{\tau_c}}\right), \quad (10\text{-}52)$$

where

$$\tau_c = \frac{C_к R r_d}{R + r_d}.$$

At that torque/moment when coil current of relay is achieved the value of spill current $i = I_c$, time t will be equal to the time for motion to start:

$$I_c = I - I e^{-\frac{t_{тр}}{\tau_c}},$$

whence obtain expression for the time for motion to start of the relay:

$$t_{тр} = \tau_c \ln \frac{I}{I - I_c} = \frac{C_к R r_d}{R + r_d} \ln \frac{K_1}{K_1 - 1}. \qquad (10\text{-}53)$$

Let us find condition, with which the time delay will have great value with a constant value of power input.

The power, consumed by circuit with the assigned voltage, will be constant in the case of the constancy of the total resistance of circuit, which let us designate by letter Z.

Then

$$Z = R + r_d \text{ and } R = Z - r_d.$$

Let us substitute into equation (10-53) instead of $R + r_d$ and R of their value; we will obtain:

$$t_{\text{тр}} = \frac{C_{\text{н}}(Z - r_d) r_d}{Z} \ln \frac{K_1}{K_1 - 1} = A(Zr_d - r_d^2),$$

where A - a constant value.

We differentiate last/latter expression with respect to $r_d$ and equate derivative with zero; we have:

$$\frac{dt_{\text{тр}}}{dr_d} = Z - 2r_d = 0 \text{ or } R = r_d.$$

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Consequently, the great time delay with the assigned voltage will occur in the case of the equality of resistor/resistances R and $r_d$.

For obtaining the greatest time for motion to start with a constant value of power input, the winding of relay

must fill whole winding space of coil.

In this case the ratio of the inductance of winding to its resistor/resistance is the value of virtually constant, not depending on turn number.

To Fig. 10-31, is given the curve of the dependence of the time for motion to start of relay in relative unity on the value of the relation of resistor/resistances $r_d/R$.

From this curve it follows that during a change of the relation of these resistor/resistances within limits from 0.7 to 1.3 the time for motion to start of relay decreases in all by 3o/o.

Let us substitute into formula (10-53) instead of $r_d$ its value; we will obtain for the greatest time for motion to start of relay the following expression:

$$t_{\text{тр. макс}} = \frac{C_K R}{2} \ln \frac{K_1}{K_1 - 1} = \frac{C_K C w^2}{2} \ln \frac{K_1}{K_1 - 1} = \frac{C n_1}{2} \ln \frac{K_1}{K_1 - 1}, \quad (10\text{-}54)$$

where the product of the capacitance/capacity (in farads) $C_K$ by $w^2$ is marked by letter $n_1$:

$$n_1 = C_K w^2. \quad (10\text{-}55)$$

The power, consumed by relay, is equal to:

$$P = \frac{U^2}{4R},$$

whence

$$R = \frac{U^2}{4P}.$$

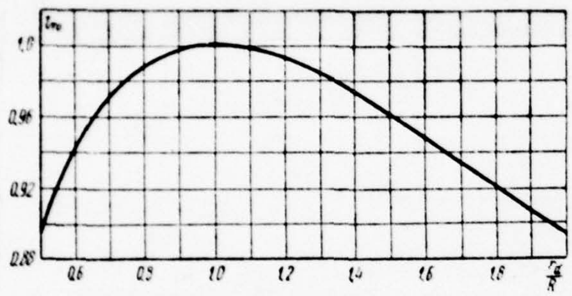


Fig. 10-31. Curved of the dependence of the time delay on the relation of resistor/resistances $r_d/R$.

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Let us substitute into equation (10-54) instead of R its value; we will obtain:

$$t_{\text{тр. макс}} = \frac{C_{\text{к}}U^2}{8P} \ln \frac{K_1}{K_1 - 1}. \qquad (10\text{-}56)$$

With a decrease in the safety factor, time for motion to start increases; however from the considerations of reliability value $K_1$ should not be taken less than two.

If we accept value $K_1$ equal to two ($K_1 = 2$), then

$$t_{\text{тр. макс}} = 0{,}346 C_{\text{к}}R = 0{,}0217 \frac{C_{\text{к}}U^2}{P_{\text{с}}}, \qquad (10\text{-}56\text{a})$$

where $P_C$ is power of the function of relay.

From formula (10-56) it follows that the greatest touching time during actuation is directly proportional to the capacitance of the capacitor and the square of the battery voltage and inversely proportional to the relay actuating power.

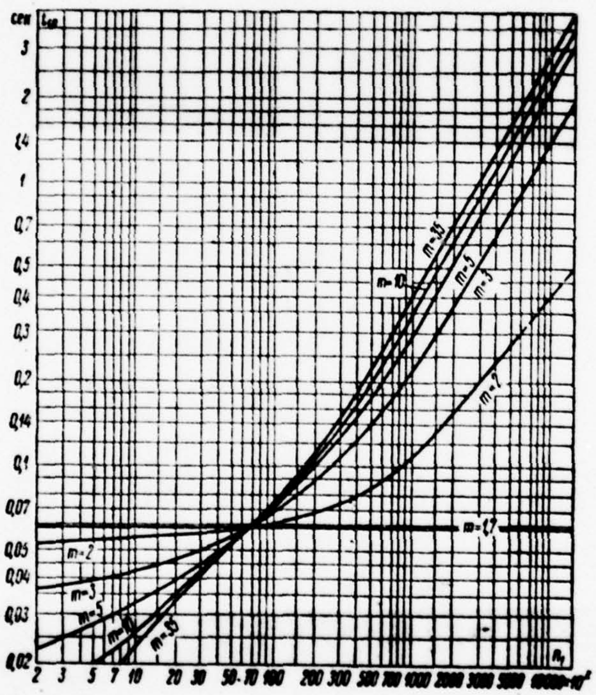


FIG. 10.32.

Fig 10.32. Curved of the dependences of the time delay of the type RKN on the value of coefficient $n_1$ at the different values of magnitude m and $K_1 = 2$.

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This formula does not consider the effect of inductance, of eddy currents, saturation of steel and time of the motion of armature. Therefore for timing of the function of the standard relays, shunted by capacitance/capacity, more accurate results gives the graphoanalytical method, constructed on experimental materials.

To Fig. 10.32, are given the curves of dependence of the time of operation on the value of coefficient $n_1$ for relay of the type RKN with the different values of value m and dual reserve on ampere turns.

In the absence of the common/general/total supplementary resistor/resistance $r_d = 0$ ($m = 1.7$) triggering time does not depend on capacitance of capacitor, while with the value of coefficient $n_1 = 65.10^2$, triggering time does not depend on the value of additional resistance.

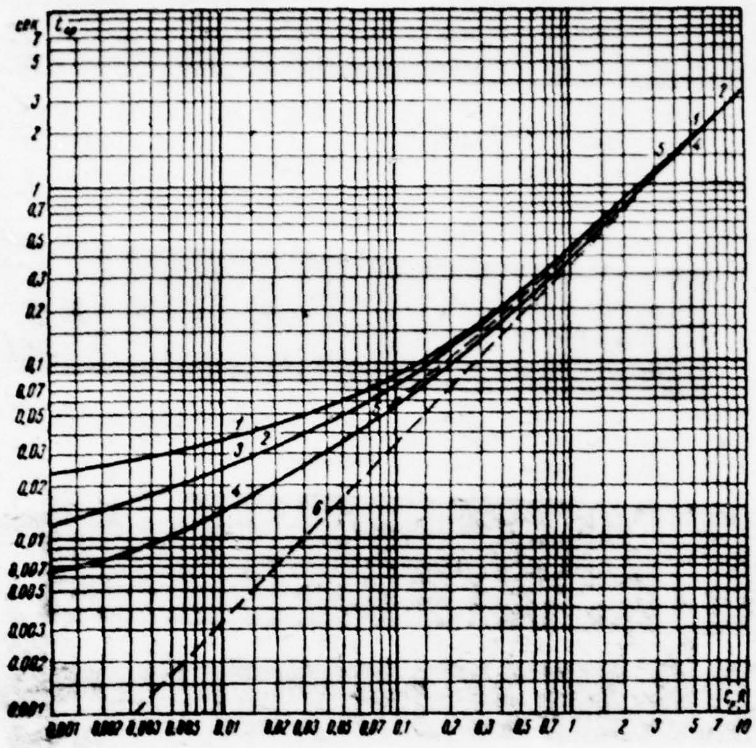

Fig. 10.33. Curved of the dependences of greatest triggering time of relay on the value of factor $C_k R$ at $K_1 = 2$ and $R = r_d$.

1 - type RPN; 2 - type RKN; 3 - type RKM1-1; 4 - type RS-13; 5 - type MKU48; - 6 - theoretical curve.

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With $n_1 < 65 \cdot 10^2$, on the contrary, it increases with an increase in the supplementary resistor/resistance. the actuating time decreases with an increase in the coefficient m, and with $n_1 > 65 \cdot 10^2$

With a constant value of the voltage of battery, the maximum time delay will occur with $r_d$ = (0.7-1.3) R.

Let us substitute into formula (10-36) instead of $r_d$ its value; we will obtain:

$$m = \frac{R + (0,7 \div 1,3)\,R}{C_m w^2} = \frac{(1,7 \div 2,3)\,C}{C_m} = \frac{1,7 \div 2,3}{k_s} \approx 2,8 \div 3,8.$$

Consequently, with value m $\approx$ 3.3 time delay has great value.

For determining the time delay with the aid of these curves, it is necessary to preliminarily find value $n_1$ with the aid of formula (10-55).

Figures 10-33 gives the curves of the dependences of greatest triggering time on the value of product $C_K R$ for the relay of types RPN, RKN, RKM-1, RS-13 and MKU-48 at dual reserve on ampere-turns and R $\approx$ $r_d$.

For a comparison to Fig. 10-33 by dotted line is shown theoretical curve (6), constructed according to formula (10-56a).

From Fig. 10-33, it follows that at the low values $C_K$ a formula (10-56a) gives very large error.

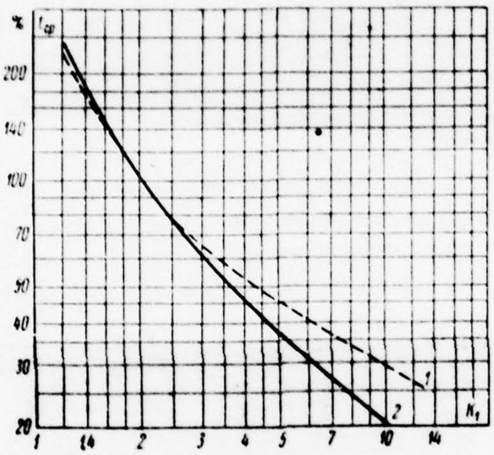


Fig. 10.34. Curved of the dependence of the time delay on the safety factor on ampere turns.

1 - type RPN; 2 type RKN.

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Therefore for timing of the function of relay, it is possible to use formula (10-56a) only when the value of

time constant $C_kR$ is more than five ($C_kR>5$).

Triggering time of the different types of relay at values $C_kR>0.1$ differs from each other comparatively little; therefore the curves Fig. 10-33 it is possible to use for the approximate determination of triggering time of any relays of the valve type, approximately analogous in size/dimensions and constructions.

The given above curves of the time delay are constructed for the dual safety factor on ampere-turns. For determining the time delay at other values $K_3$ Fig. 10-34 gives the curves of the dependences percentage change in triggering time on the value of the safety factor.

b) Shunting by the capacitance/capacity of resistor/resistance, connected in series with the winding of relay.

This diagram (Fig. 10-35) frequently is applied for an increase in speed of response of polar relays and is called "Maxwell's earth/ground". In telephone equipment this

diagram is applied rarely, since capacitance of capacitor is obtained by comparatively large.

Equation for growth curve of coil current of the relay, connected in series with the resistor/resistance, shunted by capacitance/capacity, very complicatedly and cannot be solved relative to time. Therefore, for timing of the function of standard relays to considerably conveniently use graphoanalytical method.

Figures 10-36 gives the curves of the dependences of triggering time on the value of coefficient $n_1$ with the different values of coefficient of m and dual reserve on ampere-turns for relay of the type RKN. (At the turn number of winding, equal to 10.000, value $n_1$ is numerically equal to capacitance of capacitor in μF x $10^2$).

From Fig. 10-36, it follows that a considerable increase in speed of response can be obtained only at the relatively larger values of supplementary resistor/resistance.

To each value of supplementary resistor/resistance corresponds its advantageous value of the capacitance of capacitor, with which triggering time will be minimum. With

an increase in the supplementary resistor/resistance, the value of the most favorable capacitance/capacity decreases.

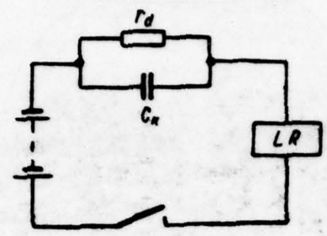


Fig. 10.35. Diagram "Maxwell's earth/ground".

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For determining the most advantageous value of capacitance of capacitor, it is possible to use following formula [L. 10-20]:

$$C_K = \frac{L \cdot 10^6}{R r_d}, \qquad (10\text{-}57)$$

where $C_K$ is a capacitance/capacity in μF and L - inductance of the winding of relay in H.

For a comparison to Fig. 10-37, are given the curves of the dependences of triggering time on the value of coefficient m in the absence of condenser/capacitor ($C_K$ = 0) and at the most advantageous value of capacitance of

capacitor ($C_K$ = $L/Rr_d$).

From figure it follows that the capacitance/capacity in all cases increases speed of response of relay; however the greatest effect the diagram "of Maxwell's earth/ground" gives at the large values of supplementary resistor/resistance.

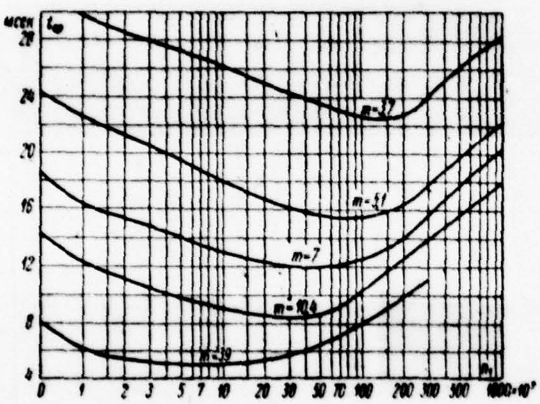


Fig. 10.36.

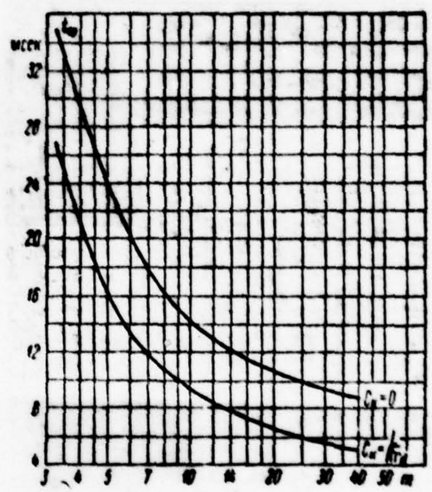

Fig. 10.37.

Fig. 10.36. Curved of the dependences of the time delay of the type RKN on the value of coefficients $n_1$ and m in diagram "Maxwell's earth/ground".

Fig. 10.37. Curved of the dependences of the time delay of the type RKN on the value of coefficient m at most

favorable values of the capacitance/capacity, shunting supplementary resistor/resistance.

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10-10. Examples.

1. Let us determine time for motion to start of relay, loaded by one stud switch of type RKN with power input 0.5 computers and dual reserve on ampere-turns.

Capacity, necessary for switching of a contact group of the type RKN, we find from the mechanical characteristic of relay of the type RKN on Fig. 2-16:

$$A \approx 5{,}0\ \Gamma\cdot см = 0{,}005\ к\Gamma\cdot см.$$

The time for motion to start of relay we determine with the aid of formula (10-8); we obtain:

$$t'_{\text{тр}} = \frac{1{,}09A'}{P} = \frac{1{,}09 \cdot 0{,}005}{0{,}5} = 0{,}0109 \text{ сек} = 10{,}9 \text{ мсек}.$$

2. Let us determine time of motion of armature of relay of type RKN with course $\delta$ = 0.9 mm and constant value of net force of attraction, equal to $F_{\text{Э}} - F_{\Pi}$ = 50 g; $c_1$ = 21 mm.

The moment of the inertia of armature is equal to the sum of the moments of the inertia of its horizontal and vertical parts. Vertical part of the armature for simplification to present in the form of the equivalent parallelepiped in size/dimension 20.6 x 22 x 2 mm. Whole of the vertical part of armature Q = 2.06•2,2•0.2•7.8 = 7.1 g. The length of the vertical part of the armature is equal to 22 mm.

Moment of the inertia of the vertical part of the armature relative to rotational axis

$$J_1 = \frac{ml^2}{3} = \frac{7{,}1 \cdot 2{,}2^2}{3 \cdot 981} = 11{,}7 \cdot 10^{-3} \text{ г} \cdot \text{см} \cdot \text{сек}^2.$$

The horizontal part of the armature can be divided into five rectangular prisms, the sum of the moments of inertia of which relative to rotational axis is equal to 7•10⁻³ to g•cm•s². Consequently, the common/general/total moment of the inertia of the armature of relay of the type RKN relative to rotational axis is equal to 18.7•10⁻³ to g•cm•s².

Time of the motion of the armature of the relay

$$t_{дв} = \sqrt{\frac{2\cdot 18{,}7\cdot 0{,}09\cdot 10^{-3}}{2{,}1^2\cdot 50}} \approx 3{,}9\cdot 10^{-3} \text{ сек.}$$

3. Let us determine triggering time of normal relay of type RPN, connected in series with resistor/resistance in 1900 ohm. Winding impedance of relay 500 ohm, turn number 10.500.

Relay is loaded by two contact groups u (switching). Course of armature 1.1 mm, the thickness of nonmagnetic antistick strip 0.3 mm. The adjustment of relay is normal. The ampere-turns of the function of relay are equal to 110. Nominal voltage of battery 60 v.

The working ampere-turns of relay with the nominal voltage of battery are equal to:

$$AW = \frac{Uw}{R + r_d} = \frac{60 \cdot 10\,500}{500 + 1900} = 262 \text{ aw.}$$

Safety factor on the ampere-turns

$$K_1 = \frac{AW}{0{,}8 \cdot AW_c} = \frac{262}{0{,}8 \cdot 110} = 2{,}98.$$

Value of coefficient m according to formula (10-36)

$$m = \frac{R + r_d}{C_m w^2} = \frac{500 + 1900}{2{,}7 \cdot 10^{-9} \cdot 10\,500^2} = 8{,}1.$$

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With the aid of values $K_1$ and m we find, from the curves of Figs. 10-11 time of release of relay. Circuit closing contacts wear/operate through 9.6 ms, and breaking contacts - through 8.5 ms.

4. Normal relay of type RPN is loaded by two contact groups u. Course of armature 1.1 mm, the height/altitude of nonmagnetic antistick strip 0.3 mm. Ampere-turns of the function of relay 100. Relays must work through resistor/resistance in 2000 ohm. It is necessary to calculate the winding of relay in such a way that the contact time of interrupting would not exceed 9 ms. Voltage of battery 60 v.

For obtaining the maximum speed of function, we take the safety factor on ampere-turns $K_1$ = 2. From the curves

Fig. 10-11 we find the point of the intersection of line, which corresponds to assigned triggering time (9 ms), from curve for the dual safety factor. To this point corresponds the value of coefficient of m = 18.

With the aid of formula (10-46) we find the turn number of the winding:

$$w=\frac{U}{0,8K_1AW_cC_mm}=\frac{60}{0,8\cdot 2\cdot 110\cdot 2,7\cdot 10^{-6}\cdot 18}=7000.$$

The total resistance of circuit must be equally to:

$$R+r_d=\frac{Uw}{0,8K_1AW_c}=\frac{60\cdot 7000}{0,8\cdot 2\cdot 110}=2380\ \text{ом}.$$

Consequently, the winding of relay must resistive

$$R=2380-2000=380\ \text{ом}.$$

If we accept the height/altitude of the winding/coil of equal about 3.5 mm, then according to diagram Fig. 6-4 with turn number 7000 winding impedance will be equal to 360 ohm. Wire d = 0.13 mm of the brand PEL. Thus, for providing assigned triggering time it is necessary to include/connect consecutively from relay the supplementary resistor/resistance

$$r_d'=380-360=20\ \text{ом}.$$

This resistor/resistance can be placed in the form of the second double winding to the coil of relay.

5. Let us determine triggering time of normal relay of type RKN, connected in series with resistor/resistance 700 ohm. Winding impedance of relay 800 ohm, turn number 14.300, the spill current of relay 17 mA. Value $C_H$ = $2.25 \cdot 10^{-6}$ ohm. Nominal voltage of batteries 60 v.

Value of coefficient m according to formula (10.36)

$$m = \frac{R + r_d}{C_m w^2} = \frac{800 + 700}{2{,}25 \cdot 10^{-6} \cdot 14\,300^2} = 3{,}26.$$

**The safety factor during the nominal rating of work will be equal to:**

$$K_1 = \frac{U}{I_c (R + r_d)} = \frac{60}{0{,}017 \cdot 1500} = 2{,}35.$$

The **values** of **quantity** $t'_{K1}$, **according** to tables 10-1, for the circuit closing contacts of relay of the type RKN are equal to 220 ms, for breaking 200 ms.

Triggering time of the circuit closing contacts of relay according to formula (10-50b)

$$t_{cp} \approx \frac{t'_{K1}}{\sqrt{K_1^2 \sqrt{m^3}}} = \frac{220}{\sqrt{2{,}35^2 \sqrt{3{,}26^3}}} = 25{,}2 \text{ мсек}.$$

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Triggering time of the breaking contact

$$t_{\text{cp}} \approx \frac{200}{8,76} = 22,8 \text{ мсек.}$$

6. Let us determine time delay of type RPN, shunted by capacitance/capacity in 100 μF. The winding of relay has 57.000 turns of wire as a diameter 0.05 mm of the brand PEL. Winding impedance 21,600 ohm. The current of functioning of relay 1.15 mA.

The value of product $C_K R$ is equal to:

$$C_{\text{к}}R = 100 \cdot 10^{-6} \cdot 21\,600 = 2,16.$$

From the curves Fig. 10-33 we find the time delay with the dual coefficient of the reserve

$$t_{\text{cp}} = 0,85 \text{ сек.}$$

The voltage of battery must be equally

$$U = 2 \cdot 1,15 \cdot 10^{-3} \cdot 2,21 \cdot 600 = 100 \text{ в.}$$

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Chapter Eleven

RELEASING TIME OF RELAYS.

11-1. Switch-off transients of relay.

The disconnection of relay can be produced either by opening (by disruption) relay circuit, or by the shorting of its winding. Let us examine first the second method.

If we disregard scattering, then for the case of the shorting of the winding of relay it is possible to write following the equations:

$$iR+\frac{d\Psi}{dt}=iR+w\frac{d\Phi'}{dt}=0, \qquad (11\text{-}1)$$

where R - winding impedance and $\Phi'$ - the magnetic flux of relay with the pullled armature.

At zero time, at $t = 0$, $i = U/R = I_y$ and $\Phi' = \Phi'_y$. The value of $\Phi'_y$ is determined in accordance with $I_y$ from the curve of dependence of $\Phi'$ on aw (see Fig. 10-1).

The solution of this problem we find also by conditional linearization, replacing nonlinear dependence $\Phi' = f$ (aw) by straight line, passing through point b, i.e., set/assuming the inductance of constant ($\Phi' w = L_y i$).

In this case equation (11-1) can be rewritten as follows:

$$\frac{\Phi' w}{L_y} R + w \frac{d\Phi'}{dt} = 0. \qquad (11\text{-}2)$$

Solution to this equation gives:

$$\Phi = \Phi'_y e^{-\frac{t}{\tau'}}, \qquad (11\text{-}3)$$

where $\tau'$ - the time constant of relay with the pulled armature:

$$\tau' = \frac{L'_y}{R}.$$

Equation (11-3) gives the law of the decrease of magnetic flux in the magnetic circuit of relay with the shorting of its winding, if we count the inductance of constant.

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Through time $t = \tau'$ after the shorting of winding, the magnetic flux of relay decreases to value $0.368 \cdot \Phi_y$, while through time $t = 3\tau$, it will be equal to $0.05 \cdot \Phi_y'$.

11.2. Time of releasing with the shorting of the winding of relay.

The releasing time of relay is composed of two those who comprise: the time, necessary for reduction in current in winding down to the critical value $I_{OT}$, by which the armature of relay begins to move, this time is called the time of kick-off $t''_{TP}$ - and the time, necessary for armature travel from kick-off time to closing/shorting or interrupting of the corresponding contact of relay, called the time of motion $t''_{дв}$ :

$$t_{от} = t'_{тр} + t'_{дв}. \quad (11\text{-}4)$$

The value time for motion to start at release/tempering, if we disregard eddy-current effect and

remanent induction, it is possible to determine from formula (11-3). At that moment when the magnetic flux of relay after the shorting of winding decreases to the flow value of release/tempering $\Phi = \Phi_{OT}$, time t will be equal to the time for motion to start:

$$\Phi_{от} = \Phi_{у} e^{-\frac{t_{тр}}{\tau'}},$$

whence find formula for the time for motion to start (with release/tempering) of the armature of relay with the shorting of its winding, if we disregard eddy-current effect and hysteresis:

$$t''_{тр} = \tau' \ln \frac{\Phi_{у}}{\Phi_{от}}. \qquad (11\text{-}5)$$

If we disregard saturation became magnetic circuits, then

$$t'''_{тр} = \tau' \ln \frac{I}{I_{от}}. \qquad (11\text{-}6)$$

where $I_{OT}$ is a current of the release/tempering of relay.

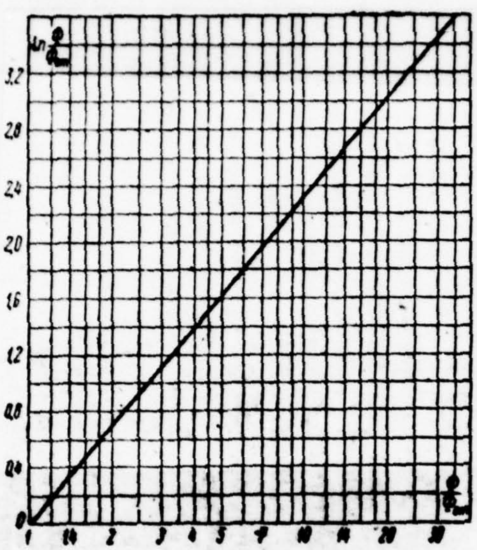


Fig. 11.1. Curved of the dependence of the constant of action on the relation $\Phi/\Phi_{OT}$.

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For the facilitation of the calculations for Fig. of 11-1, is given the curve of dependence $\ln\frac{\Phi}{\Phi_{OT}}$ on value $\frac{\Phi}{\Phi_{OT}}$; from this curve it follows that with an increase in the relation $\frac{\Phi}{\Phi_{OT}}$ the releasing time will increase.

Account of the saturation of steel of magnetic circuit.

For determining the releasing time of relay, taking into account the nonlinearity of the curve of magnetization and remanent induction, it is necessary to use demagnetization curve of the magnetic circuit of relay with the pulled armature, which is shown to Fig. 11.2a. The solution is better anything to conduct by graphic method.

From equation (11-1) we find:

$$dt = -\frac{w}{iR}d\Phi = -\frac{w^2}{R}\frac{d\Phi}{iw}.$$

With the aid of curved $\Phi = f(aw)$ on Fig. 11.2b we construct dependence $\Phi = f\left(\frac{1}{aw}\right)$.

The time, during which the flow decreases from the steady (initial) value at the pulled armature $\Phi_y$ to the flow value of the release/tempering of relay $\Phi_{от}$, is equal to:

$$t_{тр}' = \frac{w^2}{R}\int\limits_{\Phi_y}^{\Phi_{от}}\frac{d\Phi}{iw}. \qquad (11\text{-}7)$$

The integral of equation (11.7) is graphically area S, limited by curve and the axis of the ordinates between

points $\Phi_y$ and $\Phi_{or}$ to Fig. 11.2b.

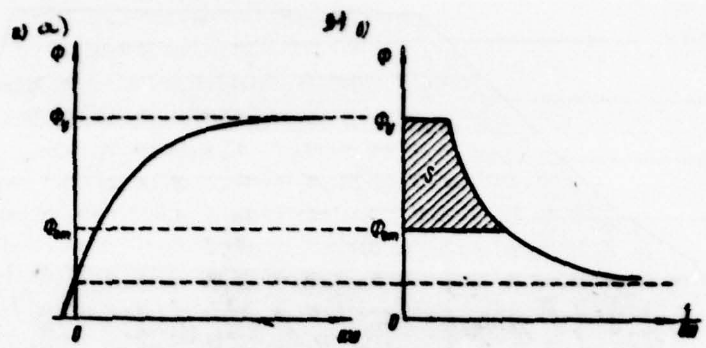

Fig. 11.2. Curved for determining the releasing time of relay by graphic method.

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These formulas do not consider eddy-current effect, which retard the decrease of flow in magnetic relay circuit after the disconnection of its winding. Let us designate the elongation of the time of kick-off, caused by the eddy currents by $t'_{\text{B}}$ then the common/general/total expression for the time of kick-off of the armature of relay with release/tempering will have the following form

$$t'_{\text{тр}} = t'''_{\text{тр}} + t'_{\text{в}} = \frac{L'}{R + r_{\text{ш}}} \ln \frac{\Phi_y}{\Phi_{\text{от}}} + t'_{\text{в}}. \qquad (11\text{-}8)$$

11.3. Releasing time during interrupting of the circuit of the winding of relay.

Disregarding the effect of spark (or arc) on contacts, it is possible to count that during interrupting (disruption) of current circuit in the winding of relay disappears instantly. In that case, if we disregard the effect of remanent induction, the time for motion to start of the armature of relay with release/tempering, it would seem, must be equal to zero. However, virtually time for motion to start has finite value. Is explained this to the fact that with disconnection in the massive parts of the magnetic circuit of relay appear the eddy currents, which retard the disappearance of magnetic flux passing through the armature of relay. Eddy currents in armature and base are relatively low, their effect on releasing time in many instances can be disregarded; therefore time for motion to start depends mainly on size/dimensions and the material of core and housing of relay. Core can have rectangular as well as round cross-section, a housing of relay it largely has rectangular cross section.

Let us examine eddy-current effect on the releasing time of relay [1. 4-11, 11-1, 11-2, 11-3, 11-4].

As is known, on the basis of the equations of Maxwell, problem it is possible to reduce to the following equation:

$$\nabla^2\overline{H} - \gamma\mu\mu_0\frac{\partial\overline{H}}{\partial t} = 0, \qquad (11\text{-}9)$$

where $\nabla^2$ - the operator of Laplace, $\overline{H}$ - the vector of magnetic intensity, $\gamma$ - the specific conductivity of core and $\mu$ - relative magnetic permeability.

A) the magnetic circuit of round cross-section.

Expressing fundamental equation in cylindrical coordinate system and taking into account that H is function only r and t, we find expression for the magnetic flux, which passes through the section of the core:

$$\Phi = 4\Phi_0 \sum_{i=1}^{\infty} \frac{1}{x_i^2} e^{-\frac{x_i^2 t}{\gamma\mu\mu_0 r^2}}, \qquad (11\text{-}10)$$

where $\Phi_0 = 4\pi\mu\mu_0 H_0 r^2$ - the initial value of magnetic flux in core (at cutoff), r - a radius of core and $x_i$ - the roots of the transcendental equation $J_0(x_i)$, which usually are given in the tables of the Bessel functions of the first zero-order kind (in the presence of i = 1 $x_i$ = 2, 4048: in the presence of $i=2$ $x_i=5.5201$ and in the presence of i = 3 $x_i$ = 8.6537).

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From last/latter expression it follows that the magnetic flux attenuates according to the law of logarithmic curve and can be represented by the infinite series of partial flows.

If we disregard the effect of the harmonics which attenuate very rapidly, and to be restricted only one first canoe of a series, then we will obtain:

$$\Phi = \frac{4\Phi_0}{2,405^2} e^{-\frac{2,405^2 t}{\gamma\mu\mu_0 r^2}} = 0,691\Phi_0 e^{-\frac{t}{\tau_{B1}}}. \qquad (11\text{-}11)$$

In this case, for the time constant of the decrease of flow in core, it is possible to accept the expression:

$$\tau'_{B1} = \frac{\gamma\mu\mu_0 r^2}{5,78} = \frac{\mu\mu_0 r^2}{5,78\rho_1}, \qquad (11\text{-}12)$$

where $\rho_1$ is the resistivity of steel of core.

In the case of the presence in the circuit of the magnetic circuit of air gap by length $\delta$ the relative calculated magnetic permeability of magnetic circuit will be equal to:

$$\mu_1 = \frac{\mu m_\Phi}{\mu + m_\Phi - 1}, \qquad (11\text{-}13)$$

where $\mu$ - relative permeability of the material of core (they stopped) and $m_\Phi$ - relative permeability of the form of magnetic circuit.

If the length of air gap is small in comparison with its section, then, disregarding scattering, we obtain for the relative permeability of form the following expression:

$$m_\Phi = \frac{l + \delta}{\delta},$$

where $l$ - the length of the steel core of magnetic circuit.

Let us substitute into equation (11-13) instead of $m_\Phi$ its value; we obtain:

$$\mu_1 = \frac{\mu(l+\delta)}{\mu\delta + l} \approx \frac{\mu l}{\mu\delta + l}. \qquad (11\text{-}13a)$$

Value $\delta$ in numerator we disregard, since it is small in comparison with $l$.

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Substituting in equation (11-12) instead of $\mu$ the value of the calculated magnetic permeability of magnetic circuit $\mu_1$ and set/assuming at the pullled armature value $\delta$ equal to the height/altitude of the plug of loosening $\delta_0$, we obtain for the time constant of the core of the relay of round cross-section the following expression:

$$\tau_{B1}' = \frac{\mu\mu_0 (l+\delta_0) r^2}{5,78\rho_1 (\mu\delta_0 + l)} \approx \frac{\mu\mu_0 l r^2}{5,78\rho_1 (\mu\delta_0 + l)}. \qquad (11\text{-}12a)$$

If we disregard reluctance they became ($\mu \approx \infty$), then

$$\mu_1 = \frac{\mu l}{\mu\delta_0 + l} = \frac{l}{\delta_0 + l/\mu} \approx \frac{l}{\delta_0},$$

time constant of the core of round cross-section

$$\tau_{B1}' = \frac{\mu_0 l r^2}{5,78\rho_1\delta_0}. \qquad (11\text{-}12б)$$

With the optimum relationship/ratio of the values of the reluctances of steel and air gap, we have: 111. In this case the time constant of the core of round cross-section will be equal to:

$$l = \mu\delta_0.$$

On the other hand, the time constant of the core of round cross-section will be equal to:

$$\tau_{B1}' = \frac{\mu\mu_0 r^2}{2 \cdot 5,78\rho_1} = \frac{\mu_0 l r^2}{2\delta_0 5,78\rho_1}. \qquad (11\text{-}14)$$

On the other hand, the time constant of core is equal

to:

$$\tau'_{в1}=\frac{L_{в1}}{R_{в1}}=\frac{K_{ф}w^{2}}{R_{в1}}=\frac{1}{R_{м}R_{в1}}, \qquad (11\text{-}14a)$$

where $L_{в1}$ - inductance of core, $R_{в1}$ - electrical core impedance to eddy currents and $R_{м}$- the given reluctance of the magnetic circuit (core) of relay.

If we disregard scattering, then the reluctance of the magnetic circuit

$$R_{м}=\frac{l}{\mu\mu_{0}S}+\frac{\delta_{0}}{\mu_{0}S}=\frac{l+\mu\delta_{0}}{\mu\mu_{0}\pi r^{2}}.$$

Substituting into equation (11-14a) instead of $R_{м}$ its value, we obtain:

$$\tau'_{в1}=\frac{\mu\mu_{0}\pi r^{2}}{(l+\mu\delta_{0})R_{в1}}. \qquad (11\text{-}14б)$$

Equalizing expressions (11-12a) and (11.14б), we obtain for resistor/resistance to the eddy currents of the core of round cross-section the following expression:

$$R_{в1}=\frac{5{,}78\pi\rho}{l}. \qquad (11\text{-}15)$$

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If the surface of pole $S_{п}$ is greater than the section of core $S_{c}$, then the value of the clearance $\delta'_{0}$ must be

led to the case of the equality of these areas. The reduced length of clearance will be equal to:

$$\delta_0 = \delta_0' \frac{S_c}{S_n}.$$

From equation (11-11) we find expression for the time for motion to start of armature during interrupting (break) of the circuit of the winding of the relay:

$$t_{\text{в1}}' = \tau_{\text{в1}}' \ln 0{,}691 \cdot \frac{\Phi}{\Phi_{\text{от}}}, \qquad (11\text{-}16)$$

where $\Phi_{\text{от}}$ - the flow with which the relay releases its armature.

B) the magnetic circuit of flat/plane section.

Solving equation (11-9) by Fourier's method, we find for magnetic flux in the magnetic circuit of flat/plane section the following expression:

$$\Phi = \Phi_0 \frac{64}{\pi^4} \sum_m^\infty \sum_n^\infty \frac{1}{m^2 n^2} e^{-k\lambda_i t}, \qquad (11\text{-}17)$$

where

$$\lambda = \pi^2 \left(\frac{m^2}{a^2} + \frac{n^2}{b^2}\right) \quad \text{and} \quad k = \frac{1}{\mu\mu_0\gamma}.$$

In these formulas a and b - the side of rectangle (section of magnetic circuit), m and n - train of odd numbers.

Consequently, magnetic flux in core is the sum of the infinite number of flows (harmonics) with the decreasing amplitude, that damp on exponential curves.

The upper harmonics attenuate extremely rapidly as a result of quadratic effect and ordinal number on damping rate. Therefore total flow in the core through very short time after the disconnection of winding is determined that mainly, by the fundamental wave. The magnetic flux, created by the fundamental wave, is equal to:

$$\Phi_1 = \frac{64}{\pi^4}\Phi_0 e^{-k\lambda_1 t} = 0{,}66\Phi_0 e^{-\frac{t}{\tau'_{в2}}}. \qquad (11\text{-}18)$$

For the time constant of the decrease of flow in core, it is possible to accept the expression:

$$\tau'_{в2} = \frac{1}{k\lambda_1} = \frac{\mu\mu_0\gamma}{\pi^2\left(\frac{1}{a^2}+\frac{1}{b^2}\right)} = \frac{\mu\mu_0 a^2 b^2}{\pi^2\rho_1(a^2+b^2)}. \qquad (11\text{-}19)$$

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If in the magnetic circuit of magnetic circuit is air gap by length $\delta_0$, then, substituting in expression (11-19)

instead of μ the calculated permeability of magnetic circuit $\mu_s$ from equation (11-13a), we obtain for the core of the rectangular cross section:

$$\tau'_{B2} = \frac{\mu\mu_0 (l+\delta_0) a^2b^2}{(\mu\delta_0 + l)\pi^2\rho_1(a^2+b^2)} \approx \frac{\mu\mu_0 l a^2 b^2}{(\mu\delta_0 + l)\pi^2\rho_1(a^2+b^2)}. \quad (11\text{-}19a)$$

If we disregard reluctance they became ($\mu \approx \infty$), then the time constant of the core of rectangular cross section will be equal to:

$$\tau'_{B2} = \frac{\mu_0 l a^2 b^2}{\delta_0 \pi^2 \rho_1 (a^2+b^2)}. \quad (11\text{-}19б)$$

In the case of the optimum relationship/ratio of the values of the reluctances of steel and air gap $l - \mu\delta_0$ the time constant of the core of rectangular cross section will be equal to:

$$\tau'_{B2} = \frac{\mu\mu_0 a^2 b^2}{2\pi^2\rho_1(a^2+b^2)} = \frac{\mu_0 l a^2 b^2}{2\pi^2\rho_1(a^2+b^2)\delta_0}. \quad (11\text{-}19в)$$

On the other hand, the time constant of the core

$$\tau'_{B2} = \frac{L_{B2}}{R_{B2}} = \frac{1}{R_M R_{B2}} = \frac{\mu\mu_0 ab}{(l+\mu\delta_0)R_{B2}}, \quad (11\text{-}20)$$

where $L_{\beta 2}$ is inductance of core, $R_{\beta 2}$ - electrical core impedance to eddy currents and $R_M$ - the given reluctance of magnetic circuit.

Equalizing expressions (11-19c) and (11-20), we obtain

for resistor/resistance to the eddy currents of the core of rectangular cross section the following expression:

$$R_{в2} = \frac{\pi^2 \rho_1 (a^2 + b^2)}{lab}. \qquad (11\text{-}21)$$

If core is assembled from the large number of plates of sheet iron (laminated core), then

$$R_{м} = \frac{l + \mu\delta_0}{\mu\mu_0 a b_1 n} \quad \text{and} \quad R'_{в2} = \frac{\pi^2 \rho_2 (a^2 + b_1^2) n}{lab_1} \approx \frac{\pi^2 \rho_2 ab}{lb_1} = \frac{\pi^2 \rho_2 a^2}{lb} n, \qquad (11\text{-}21a)$$

where n is a number of plates (sheets) from which is assembled the core of magnetic circuit, a and $b_1$ - width and the thickness of each plate of core and $b = nb_1$ - thickness of core (packet of plates).

Value $b_1^2$ in the numerator of equation (11-21a) we disregard, since it is small in comparison with $a^2$.

The relation of resistor/resistances $R'_{\beta 2}$ and $R_{\beta 2}$, is equal to:

$$\frac{R'_{в2}}{R_{в2}} = \frac{\rho_2 n^2 (a^2 + b_1^2)}{\rho_1 (a^2 + b^2)} \approx \frac{\rho_2 n^2 a^2}{\rho_1 (a^2 + b^2)}. \qquad (11\text{-}22)$$

If core has square section (a = b), then

$$\frac{R'_{в2}}{R_{в2}} = \frac{\rho_2 n}{2\rho_1}. \qquad (11\text{-}22a)$$

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Consequently, resistor/resistance to the eddy currents of the laminated core of square section at equal values $\rho_1$ = $\rho_2$ in $n^2/2$ times is more massive (nonlaminated).

From equation (11-18) we find expression for the time for motion to start of armature during interrupting of the circuit of the winding of the relay:.

$$t'_{в2} = \tau'_{в2} \ln 0{,}66 \frac{\Phi}{\Phi_{от}}. \qquad (11\text{-}23)$$

11-4. Elongation the time for motion to start of relay, caused by eddy currents.

The given above conclusion/derivations it is possible to use for determining the elongation of triggering time (contact/start) of the high-speed relays, caused by eddy currents.

In the case of the instantaneous onset of field, it is possible to write the following equation:

$$\Phi = \Phi_y \sum_1^{\infty} \zeta_i (1 - e^{-h\lambda_i t}), \qquad (11\text{-}24)$$

where $\Phi_y$ is the steady magnetic flux.

Disregarding harmonics, we obtain for the magnetic flux, which passes through the core of the round cross-section:

$$\Phi = \Phi_y (1 - 0{,}691 e^{-\frac{t}{\tau_в}}), \qquad (11\text{-}24а)$$

whence find formula for the elongation of the time for motion to start of relay with the core of the round cross-section, produced by eddy-current effect during the instantaneous onset of the magnetic field:

$$t_{в1} = \tau_{в1} \ln \frac{0{,}691\Phi_y}{\Phi_y - \Phi_c} = \tau_{в1} \ln \frac{0{,}691 I}{I - I_c}. \qquad (11\text{-}25)$$

For the core of rectangular cross section, the elongation of time for motion to start, produced by eddy currents during the instantaneous onset of magnetic field, is equal to:

$$t_{в2} = \tau_{в2} \ln \frac{0{,}66\Phi_y}{\Phi_y - \Phi_c} = \tau_{в2} \ln \frac{0{,}66 I}{I - I_c}. \qquad (11\text{-}26)$$

In these formulas the time constants of the growth/build-up of flow are respectively equal to:

$$\tau_{\text{в}1} = \frac{lr^2\mu\mu_0}{5.78\rho_1(\mu\delta_1 + l)} \quad (11\text{-}12a)$$

and

$$\tau_{\text{в}2} = \frac{la^2b^2\mu\mu_0}{\pi^2\rho_1(a^2 + b^2)(\mu\delta_1 + l)}, \quad (11\text{-}19a)$$

where $\delta_1$ is the given clearance of relay with the nonpullled armature.

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## 11-5. Time of the motion of the armature of relay with release/tempering.

With release/tempering the armature of the relay begins to move at that torque/moment when the force of retention $F_э$ becomes less than the mechanical load $F_П$.

The analytical method of the calculation of the motion of the armature with release/tempering is extremely complex; therefore let us examine the simplified graphic method, proposed by N. A. Lifshitz [1. 10-3].

Obtaining dependence curve of force $F_э$, which operates on armature with release/tempering from the course of armature, is extremely difficult; therefore during calculation value $F_э$ let us consider as constant, not depending on the course of armature and equal to the force of retention (Fig. 11-3a).

This assumption considerably decreases the accuracy of calculation and limits the field of its use, mainly, by the high-speed relays, which have the very slow speed of armature.

The equation of motion of armature with the release/tempering of the relay

$$F = F_n - F_э = m_1 \frac{d^2\delta}{dt^2}, \quad (11\text{-}27)$$

where $m_1$ is the reduced mass of armature and $\delta$ - the course of armature.

The curve of the dependence of net force F, which operates on the armature with release/tempering on armature travel, is shown to Fig. 11-3b.

The speed of the motion of armature is equal to $d\delta/dt$; consequently,

$$F = m_1 \frac{dv}{dt}.$$

Hence we find:

$$m_1 \frac{dv}{F} = \frac{d\delta}{v} \quad \text{or} \quad m_1 v\,dv = F\,d\delta.$$

Integrating last/latter equation, we obtain:

$$m_1 \int_0^{v_i} v\,dv = \int_{\delta_{\text{макс}}}^{\delta_i} F\,d\delta \quad \text{or} \quad \frac{m_1 v_i^2}{2} = \int_{\delta_{\text{макс}}}^{\delta_i} F\,d\delta = \text{площ.}\ ABCD.$$

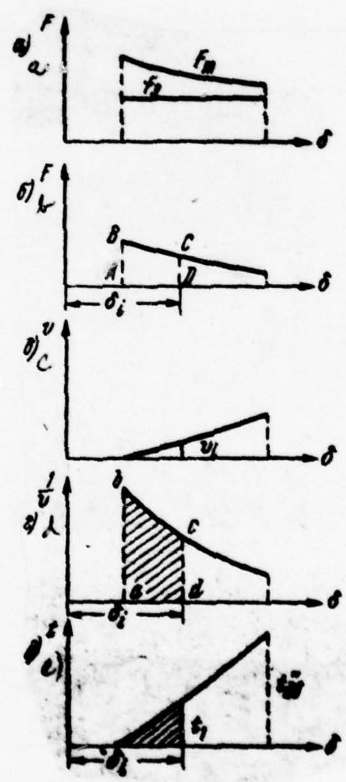


Fig. 11-3. On the calculation of the time of the motion of armature with release/tempering.

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Consequently,

$$v_i = \sqrt{\frac{2\ \text{площ.}\ ABCD}{m_1}}. \qquad (11\text{-}28)$$

Through values $v_i$, we find from Fig. 11-3c, the dependence $v_i = f(\delta)$. After constructing dependence $1/v_i = f_2(\delta)$ (Fig. 11-3d), we find:

$$t_i = \int_{\delta_{\text{мин}}}^{\delta_i} \frac{1}{v_i}\, d\delta = \text{площ.}\ abcd. \qquad (11\text{-}29)$$

In Fig. 11-3e is constructed the curve of dependence $t = f_3(\delta)$ and is shown the time of the motion of armature with release/tempering $t_{\text{дв}}$.

If we assume that net force, which operates on armature with the release/tempering of relay, is constant and does not depend on armature travel, then the time of the motion of the armature

$$t_{\text{дв}} = \sqrt{\frac{2m_1\delta}{F_{\text{п}} - F_{\text{э}}}} = \sqrt{\frac{2J\delta}{c_1^2 (F_{\text{п}} - F_{\text{э}})}}, \qquad (11\text{-}30)$$

where $m_1$ - the reduced mass of armature, is equal to $J/c_1^2$, J - the moment of the inertia of armature relative

to the rotational axis and $C_1$ - a distance from rotational axis to the axis of core.

11-6. Most advantageous sizes of quadrature winding of relay.

Time for motion to start with the release/tempering of time-lag relay, if we disregard eddy-current effect in magnetic circuit, it is expressed by the following formula:

$$t_{\text{он.тр}} = \tau'_{\kappa} \ln \frac{\Phi}{\Phi_{\text{от}}} = \frac{L'_{\kappa}}{R_{\kappa}} \ln \frac{\Phi}{\Phi_{\text{от}}} = \frac{K_0}{C_1} \ln \frac{\Phi}{\Phi_{\text{от}}},$$

where $L'_K$ and $R_K$ are inductance with the pullled armature and the resistor/resistance of quadrature winding.

For obtaining the maximum time dilation of the release/tempering of relay other conditions being equal it is necessary to have the maximum value of the time constant of quadrature winding.

Let us substitute for $K_0$ and $C_1$ of their value from expressions (4-50), (10-21), (4-27) and (6-13) and replace $D_0$ through $d_C$; we obtain [1. 11-5]:

$$t_{\text{ок.тр}} = \frac{\pi l k_з \cdot 10^{-7} d_c^2 h_к}{\delta_0 \rho (d_c + h_к)} \ln \frac{\Phi}{\Phi_{\text{от}}} = \varepsilon \frac{d_c^2 h_к}{d_c + h_к}, \qquad (11\text{-}31)$$

where $\delta_0$ - the reduced length of clearance with the pullled armature taking into account the reluctance of magnetic circuit, $d_C$ - the diameter of core, $h_K$ - the height/altitude of quadrature winding and

$$\varepsilon = \frac{\pi l k_з \cdot 10^{-7}}{\delta_0 \rho} \ln \frac{\Phi}{\Phi_{\text{от}}}.$$

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This expression is analogous with equation (10-23) for the time delay; equalizing zero derivative of $t_{OK,TP}$ in terms of $h_K$, we find the advantageous relationship/ratio between the height/altitude of quadrature winding and the diameter of core, which according to formula (10-25) is equal $h_K = 0.306 \cdot d_C$. Virtually due to the effect of the magnetic resistor/resistance of steel, the optimum height of quadrature winding will be within the limits approximately from $0.25d_C$ to $0.3d_C$.

With constant values of diameter and lengths of core, the relative time for motion to start with the release/tempering of time-lag relay (just as time for motion

to start during the function of relay) increases with an increase in altitude of quadrature winding in accordance with the curve Fig. 10-8. From this curve it follows that an increase in ratio $h_k/d_c$ is more than 0.5 irrationally, since it leads to the poor use of copper and an increase in the overall size of relay.

For obtaining the larger releasing time of relay, it is necessary to increase diameter and length of core and to maintain in this case the optimum relationship/ratio between the height/altitude of quadrature winding and the diameter of core. If we fulfill the housing of relay in the form of the second core with quadrature winding, then the releasing time of relay it can be increased almost two times.

11.7. Relationship/ratio between at times of contact/start with the release/tempering of normal and time-lags relay.

Time for motion to start during interrupting (disruption) of the circuit of the winding of normal relay with circular core is equal to:

$$t_{в} = \frac{\mu_0 l r^2}{5{,}78\rho_1\delta_0} \ln 0{,}691 \frac{\Phi}{\Phi_{от}} = \frac{\pi \cdot 10^{-7} l d_c^2}{5{,}78\rho_1\delta_0} \ln 0{,}691 \frac{\Phi}{\Phi_{от}}.$$

The ratio time for motion to start with the shorting of winding to time for motion to start during interrupting of this winding of relay, if we disregard in equation (11-16) coefficient 0.691 before the relation of flows, will be equal to:

$$\frac{t_{он.тр}}{t_{в}} = \frac{\pi l k_3 \cdot 10^{-7} d_c^2 h_к}{\rho\delta_0 (d_c + h_к)} \cdot \frac{5{,}78\rho_1\delta_0}{\pi \cdot 10^{-7} l d_c^2} = \frac{5{,}78\rho_1 k_3 h_к}{\rho (d_c + h_к)}. \quad (11\text{-}32)$$

Substituting the specific resistor/resistances of steel $\rho_1$ = (11-14)•10⁻⁸ Ω•m and of copper $\rho$ = 1.75•10⁻⁸ Ω•m, we find:

$$\frac{t_{он.тр}}{t_{в}} = (36{,}4 \div 46{,}3) \frac{k_3 h_к}{d_c + h_к}.$$

end section.

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If relay has quadrature winding from red copper tube with the optimum wall thickness, then $k_3$ = 1 and $h_к = 0{,}306 \cdot d$ then

$$\frac{t_{ок.тр}}{t_в} = (36{,}4 \div 46{,}3)\frac{0{,}306 d_c}{1{,}306 d_c} = 8{,}4 \div 10{,}7. \quad (11\text{-}32a)$$

Thus, time-lag relay with the red copper tube of optimum thickness, other conditions being equal, has approximately 8.4-10.7 times the larger time for motion to start with release/tempering than the normal unretarded relay.

For time-lag relay with quadrature winding of optimum height from the bare wire of round cross-section, this sense oscillates tentatively within limits from 6.6 to 8.4.

Time of contact/start with the release/tempering of the relay, which has $d_c = 9$ mm, h = 6.7 mm and $k_3$ = 0.6 with shorting of winding are approximately 9.3-11.8 times more than during interrupting.

Figures 11-4 gives tentative the curves of the dependences of releasing time for valve type relay with the pole piece on weight they will stop magnetic circuit with interrupting 1 and the shorting of 2 windings of the relay, loaded by one stud switch at the height/altitude of the plug of loosening 0.1 mm.

By dotted line are shown analogous curves for relay without the pole piece. The releasing time of relay can be approximately doubled in the case of the replacement of the housing of relay by the second core with quadrature winding. Other conditions being equal, for an increase in the releasing time of relay necessary to increase weight they will begin magnetic circuits.

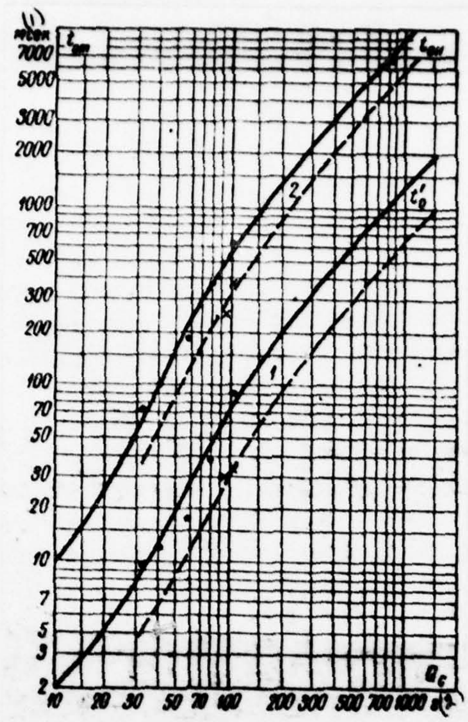


Fig. 11-4. Curved of dependences of releasing time of relay on weight of steel of magnetic circuit. 1 - release/tempering with opening of winding; 2 - Release with the shorting of winding.

Key: (1). ms. (2). g.

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11-8. Graphoanalytical method of timing of the release of relay.

The analytical method of timing of the release/tempering of relay due to the difficulty the account of the saturation of magnetic circuit, leakage fluxes, eddy-current effect, change in load and time of the motion of armature is extremely complex and is not characterized by sufficient accuracy. Therefore for timing of the release/tempering of standard relays considerably more convenient and more precise will be the graphoanalytical method, proposed by author.

The releasing time of relay with the shorting of its winding is expressed by the following formula:

$$t_{\text{от}} = \frac{L'}{R} \ln \frac{\Phi}{\Phi_{\text{от}}} + t'_{\text{в}} + t''_{\text{дв}}. \quad (11\text{-}33)$$

During interrupting of the circuit of winding, the releasing time of this relay will be, obviously, equally to:

$$t'_0 = t'_{\text{в}} + t''_{\text{дв}}. \quad (11\text{-}34)$$

Let us substitute into equation (11-33) instead of L', R, $t'_{\text{в}}$ and $t''_{\text{дв}}$ of their value; we obtain:

$$t_{\text{от}} = \frac{K_0 w^2}{R} \ln \frac{\Phi}{\Phi_{\text{от}}} + t'_0 = \frac{K_0}{C} \ln \frac{\Phi}{\Phi_{\text{от}}} + t'_0, \quad (11\text{-}33\text{a})$$

where value C depends on filling of the winding space of

coil, diameter of wire and thickness of insulation.

Let us designate by $w_{н}$ and $R_{н}$ turn number and the resistor/resistance of some winding (desirably filling whole winding space coil); then the releasing time of relay with the shorting of its winding is equally to:

$$t_{0н} = \frac{K_0 w_н^2}{R_н} \ln \frac{\Phi}{\Phi_{от}} + t_0' = \frac{K_0}{C_н} \ln \frac{\Phi}{\Phi_{от}} + t_0',$$

where

$$C_н = \frac{R_н}{w_н^2}.$$

From last/latter equation we find:

$$K_0 \ln \frac{\Phi}{\Phi_{от}} = C_н (t_{0н} - t_0').$$

Substituting in equation (11-33a) instead of $K_0 \ln \frac{\Phi}{\Phi_{от}}$ its value from last/latter expression, we obtain formula for determining the releasing time of relay with the shorting of its winding:

$$t_{от} = \frac{C_н w^2}{R}(t_{0н} - t_0') + t_0' = \frac{C_н}{C}(t_{0н} - t_0') + t_0'. \quad (11\text{-}35)$$

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The values of quantities $t_{от}$ and $t'_0$ can be easily obtained experimentally for any type of relay.

If the winding of relay is shunted by effective resistance $r_{ш}$, then the releasing time of this relay will

be equal to:

$$t_{\text{от}} = \frac{C_{\text{к}} w^2}{R + r_{\text{ш}}}(t_{0\text{н}} - t_0') + t_0'. \quad (11\text{-}36)$$

The releasing time of double-coiled relay of which one with turn number $w_{\text{к}}$ and by resistor/resistance $R_{\text{к}}$ it is shortcircuited, but another with parameters w and R it is shunted by resistor/resistance $r_{\text{ш}}$, it will be:

$$t_{\text{от}} = \left(\frac{K_0 w_{\text{к}}^2}{R_{\text{к}}} + \frac{K_0 w^2}{R + r_{\text{ш}}}\right) \ln\frac{\Phi}{\Phi_{\text{от}}} + t_0' = K_0\left(\frac{w_{\text{к}}^2}{R_{\text{к}}} + \frac{w^2}{R + r_{\text{ш}}}\right) \ln\frac{\Phi}{\Phi_{\text{от}}} + t_0.$$

Substituting in this equation for $K_0 \ln\frac{\Phi}{\Phi_{\text{от}}}$ its value, we obtain formula for timing of the release/tempering of the relay, which has one short-circuited and another shunted winding:

$$t_{\text{от}} = C_{\text{к}}\left(\frac{1}{C_{\text{кз}}} + \frac{w^2}{R + r_{\text{ш}}}\right)(t_{0\text{н}} - t_0') + t_0', \quad (11\text{-}37)$$

where

$$C_{\text{кз}} = \frac{R_{\text{к}}}{w_{\text{к}}^2}.$$

Releasing time of time-lag relay during interrupting of the circuit of winding ($r_{\text{ш}} = \infty$)

$$t_{\text{от}} = \frac{C_{\text{к}}}{C_{\text{кз}}}(t_{0\text{н}} - t_0') + t_0'. \quad (11\text{-}37\text{a})$$

With the shorting of inducing winding of time-lag relay releasing time

$$t_{\text{от}} = C_{\text{к}}\left(\frac{1}{C_{\text{кз}}} + \frac{1}{C}\right)(t_{0\text{н}} - t_0') + t_0'. \quad (11\text{-}37\text{b})$$

If relay has three windings, then the releasing time of this relay in general form can be expressed by the following formula:

$$t_{\text{от}} = C_{\text{н}}\left(\frac{w_1^2}{R_1 + r_{\text{ш1}}} + \frac{w_2^2}{R_2 + r_{\text{ш2}}} + \frac{w_3^2}{R_3 + r_{\text{ш3}}}\right)(t_{0\text{н}} - t_0') + t_0'. \quad (11\text{-}38)$$

With the shorting of all three windings releasing time

$$t_{\text{от}} = C_{\text{н}}\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)(t_{0\text{н}} - t_0') + t_0'. \quad (11\text{-}38a)$$

For timing of the release/tempering of standard relays with the aid of the given above formulas, it is necessary to have experimental curves of dependences of the releasing time of these relays during interrupting $t'_0$ and with the shorting of any winding (desirably filling whole winding space coil) $t_{0\text{н}}$ on the load of armature and value of clearance at the pullled armature (height/altitude of plug).

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11-9. Curved for timing of the release/tempering of standard relays.

The releasing time of relay of any specific type depends on the load of armature, value of clearance (height/altitude of plug) and of the magnetizing ampere-turns, which occurred before interrupting of circuit.

The value of the releasing time of relay strongly depends on the accuracy of production, thickness of the layer of finishing and quality of the assembly of magnetic contacts (joints); therefore in mass production it is very difficult to attain the uniformity of relay on the releasing time, especially time-lags relay.

For obtaining the assigned releasing time, are applied the adjustable armature plugs.

The deviation of the time of release from nominal value is allow/assumed within limits of ±30o/o, actually sometimes this deviation can reach to ±50o/o.

Other conditions being equal, the releasing time of the different contacts of one and the same relay is also different, especially for a high-speed relay. However, in view of the fact that the releasing time of the normal and deferred-action types of relay is not at all

characterized by large stability, are sufficient to be restricted to the determination of the releasing time only circuit closing contacts (i.e. the contacts, which are closed during the function of relay).

a) Relays of the type RPN.

Figures 11-5 shows the curves of the dependences of the releasing time of a normal relay of the type RPN on the load of armature with different clearances (different thickness of nonmagnetic antistick strips). The first (upper) series of curves is obtained experimentally with the shorting of the winding of relay, which fills whole winding space of coil ($C_{\text{н}} = 4{,}5 \cdot 10^{6}$ ohm); the second (lower) series of curves is obtained with disconnection (disruption) value the windings of relay.

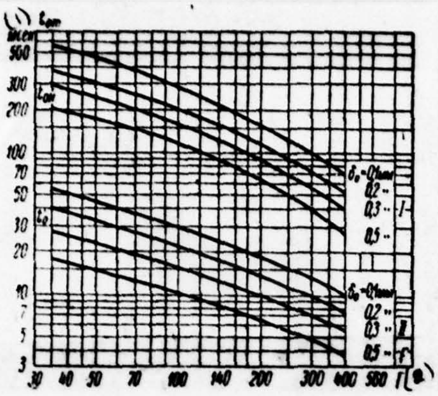

Fig. 11-5. Curved of releasing time of normal relay of type RPN ($C_{\text{м}} = 4,5 \cdot 10^{-4}$ ohm).

Key: (1). ms. (2). g.

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Measurements are conducted by magnetizing force, equal to 600 ampere-turns. Load of retention for the fundamental contact groups of relay of the type RPN are given in Table 11-1.

For timing of the release/tempering of relay of the type RPN with the aid of these curves, it is necessary preliminarily from Table 11-1 to find the load of retention

in grams, created by the contact packet of relay. Then by the value of the obtained load of retention and the thickness of nonmagnetic antistick strip to determine by the curves of Fig. 11-5 releasing time at break $t'_0$ and the shorting of winding (filling whole winding space of relay) $t_{0H}$.

Finally with the aid of formulas for those who were assigned the turn numbers and winding impedance to calculate the releasing time of relay.

Table 11-1. Loads of the retention of relay of the type RPN.

| Номер чертежа (1) | Обозначение группы (2) | Нагрузка удержания $F_y$, Г (3) | Номер чертежа (1) | Обозначение группы (2) | Нагрузка удержания $F_y$, Г (3) |
|---|---|---|---|---|---|
| 01 | *a* | 54 | 27 | *far* | 64 |
| 02 | *r* | 35 | 28 | *fra* | 54 |
| 03 | *u* | 65 | 29 | *rza* | 73 |
| 04 | *za* | 74 | 46 | *aa* | 82 |
| 05 | *zr* | 55 | 95 | *afr* | 41 |
| 07 | *ar* | 73 | 100 | *gru* | 92 |
| 10 | *rr* | 62 | 102 | *gau* | 103 |
| 11 | *zra* | 85 | 103 | *gzaa* | 96 |
| 12 | *ur* | 92 | 105 | *gua* | 83 |
| 13 | *au* | 102 | 106 | *gur* | 74 |
| 26 | *faa* | 77 | 107 | *aaa* | 119 |

Key: (1). Number of drawing. (2). Designation of group. (3). Load of retention $F_y$ g.

Table 11-2. Parameters of short-circuited and inducing windings of time-lags relay.

| (1) Тип реле | (2) Размеры короткозамкнутой обмотки | $C_{кз}$, (3) ом | $C_m$, (3) ом | (1) Тип реле | (2) Размеры короткозамкнутой обмотки | $C_{кз}$, (3) ом | $C_m$, (3) ом |
|---|---|---|---|---|---|---|---|
| РКН | $l$=12,8 мм | $9{,}15 \cdot 10^{-6}$ | $2{,}92 \cdot 10^{-6}$ | РКМ-1 | $h$ = 1 мм | $11{,}8 \cdot 10^{-6}$ | $4{,}6 \cdot 10^{-6}$ |
| › | $l$=25,5 мм | $4{,}59 \cdot 10^{-6}$ | $4{,}05 \cdot 10^{-6}$ | › | $h$ = 2 мм | $6{,}65 \cdot 10^{-6}$ | $7{,}18 \cdot 10^{-6}$ |
| › | $l$=38,0 мм | $3{,}08 \cdot 10^{-6}$ | $6{,}55 \cdot 10^{-6}$ | РКМП | $h$ = 2 мм | $8{,}36 \cdot 10^{-6}$ | $5{,}32 \cdot 10^{-6}$ |
| › | $h$=4,0 мм | $3{,}85 \cdot 10^{-6}$ | $6{,}97 \cdot 10^{-6}$ | › | $h$ = 3 мм | $6{,}10 \cdot 10^{-6}$ | $7{,}5 \cdot 10^{-6}$ |
| › | (4) Передняя щека из меди | $77{,}0 \cdot 10^{-6}$ | — | › | $h$ = 4 мм | $4{,}95 \cdot 10^{-6}$ | $11{,}85 \cdot 10^{-6}$ |
| РПН | $h$ = 1 мм | $14{,}5 \cdot 10^{-6}$ | $3{,}38 \cdot 10^{-6}$ | РЭС14 | $h$ = 1 мм | $8{,}65 \cdot 10^{-6}$ | $3{,}15 \cdot 10^{-6}$ |
| › | $h$ = 2 мм | $7{,}95 \cdot 10^{-6}$ | $4{,}35 \cdot 10^{-6}$ | › | $h$ = 2 мм | $4{,}85 \cdot 10^{-6}$ | $4{,}26 \cdot 10^{-6}$ |
| › | $h$ = 3 мм | $5{,}76 \cdot 10^{-6}$ | $5{,}86 \cdot 10^{-6}$ | › | $h$ = 3 мм | $3{,}56 \cdot 10^{-6}$ | $6{,}20 \cdot 10^{-6}$ |
| | | | | РМУ | $l$ = 17 мм | $7{,}85 \cdot 10^{-6}$ | $16{,}3 \cdot 10^{-6}$ |

Key: (1) Type of relay; (2) Size/dimensions of quadrature winding; (3) ohm; (4) front/leading jaw from copper.

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The loads of retention for relays of the type RPN, given in Table 5-12, cannot be used for timing of release/tempering, since they are given only for the calculation of the ampere-turns of retention and maintain production (certified/rating) stock.

For timing of the release/tempering of time-lags relay of the type RPN with the aid of the curves of Fig. 11-5, it is necessary to know the appropriate value of quantities $C_{кз}$. The values of these quantities are given in Table 11-2.

The releasing time of relay, other conditions being equal, depends also on the value of the magnetizing ampere-turns. Figures 11-6 gives the curves of the dependences of the releasing time of relay of the type RPN on the magnetizing ampere-turns with the different thickness of nonmagnetic antistick strips. Relays were loaded by one contact group No 03.

From the curves of Fig. 11-6, it follows that during a decrease in the magnetizing ampere-turns to 200 releasing time of relay is little affected; during a further decrease in the ampere-turns, it sharply falls.

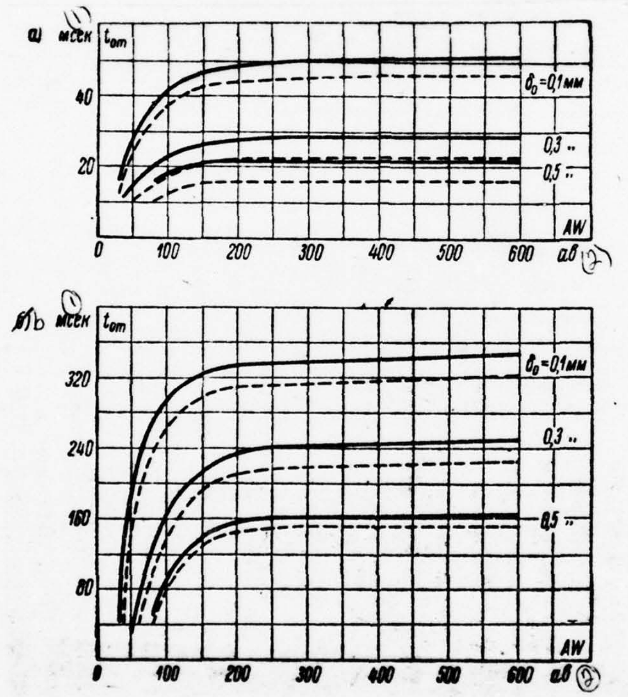


Fig. 11-6. **Curved of dependences of releasing time of relay of type RPN on magnetizing ampere-turns**: a - release/tempering with disconnection of winding; b - release/tempering with shorting of winding.

Key: (1). ms. (2). AV.

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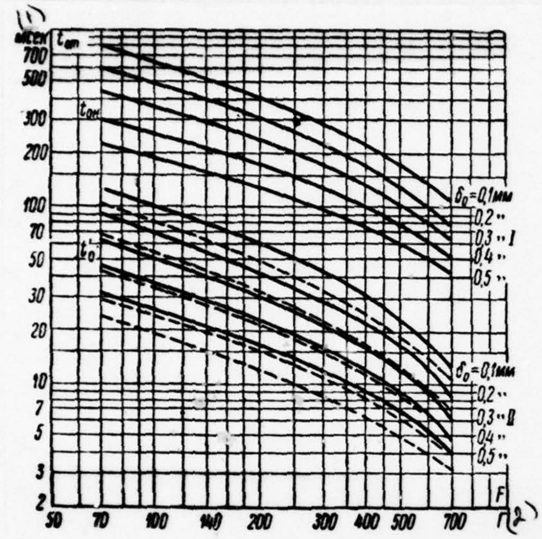


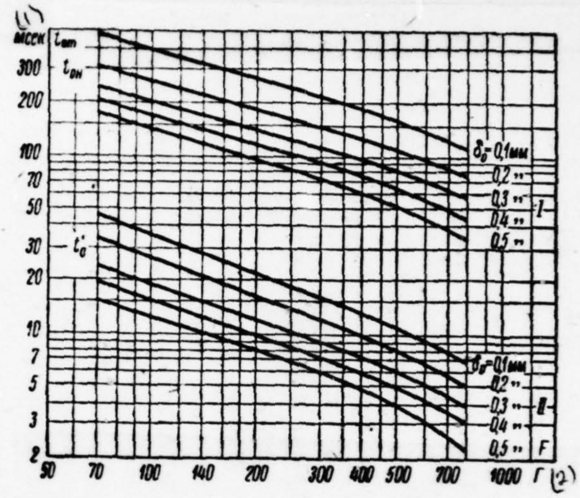


Fig. 11-8.

Fig. 11-7. Curved of releasing time of relay of type RKN ($C_H = 3{,}2 \cdot 10^{-6}$ ohm); solid lines is front/leading jaw of coil from copper; broken - front/leading jaw of coil out of getinax. I - release/tempering with the shorting of winding; II - Release with the disconnection of winding.

Key: (1). ms. (2). g.

Fig. 11-8. Curved of releasing time of relay of type RKN without pole piece. I - release/tempering with the shorting of winding; II - release/tempering with the disconnection of winding.

Key: (1). ms. (2). g.

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)
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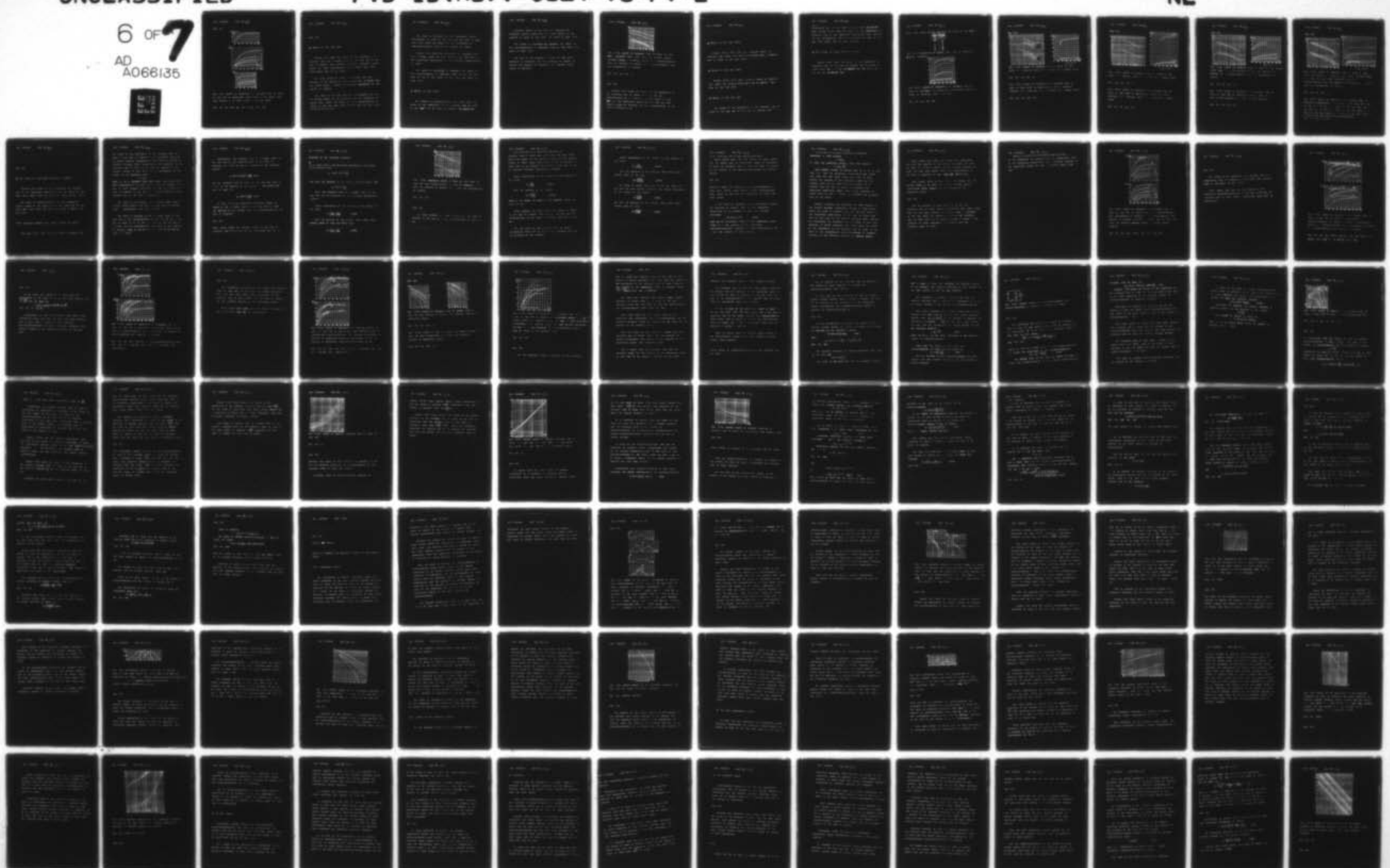

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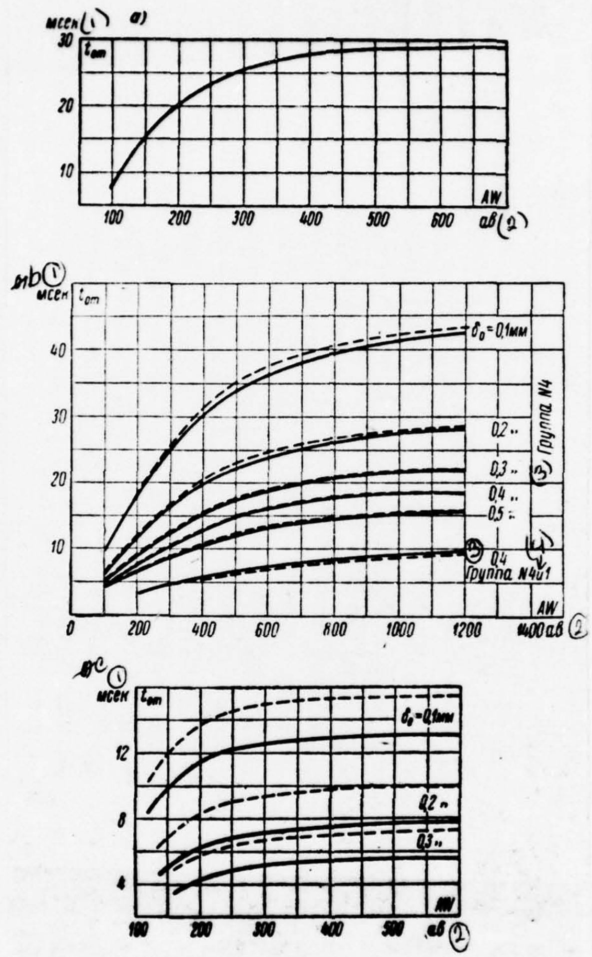


Fig. 11-9. Curved of dependences of releasing time of relay of type RKN on magnetizing ampere-turns: a is normal relay (jaw copper); b is pulse relay; c is test relay.

Key: (1). ms. (2). AV. (3). Group. (4). and.

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б) Relays of the type RKN.

Figures 11-7 shows the curves of the dependences of releasing time for a normal relay of the type RKN on the load of armature with different clearances (different plugs). Curves are taken experimentally for a normal relay with front/leading jaw of red copper.

The first series of curves is obtained with the shorting of the winding of relay, which has $C_{н} \doteq 3.2 \cdot 10^{-8}$ ohm, the second series - during interrupting (disruption) of the circuit of winding.

For relay of the type RKN with front/leading jaw out of getinax curved of the releasing time are designated by dotted line. Curves for timing of the release/tempering of relays of the type RKN, which do not have the pole piece, are given in Fig. 11-8.

The loads of retention for the fundamental contact cell/elements of relay of the type RKN are given in Table 5-13. This table one should use for determining the common/general/total load of the armature of relay.

Figures 11-9 gives the dependences of releasing time for a normal, pulse and test relay of the type RKN on the magnetizing ampere-turns at the different height/altitude of plugs.

The values of quantities $C_н$ necessary for timing of the release/tempering of time-lags relay of the type RKN with the aid of the curves of Fig. 11-7, are given in Table 11-2.

c) Relays of type RKM-1.

For timing of release/tempering Fig. 11-10 gives the curves of the dependences of the releasing time of relay of type RKM-1 on the load of armature ($C_н = 5{,}4\cdot10^{-6}$ ohm).

Tentative values of the loads of retention for elementary contact groups and the return spring of the armature of relay of type RKM-1 are given in Table 11-3.

The values of quantities $C_{\text{км}}$ necessary for timing of the release/tempering of time-lags relay of type RKM-1, are given in Table 11-2.

The load of the armature of relay of type RKM-1 depending on tolerances for the thickness of contact of springs and accuracy of adjustment can oscillate within limits of ±20-40o/o.

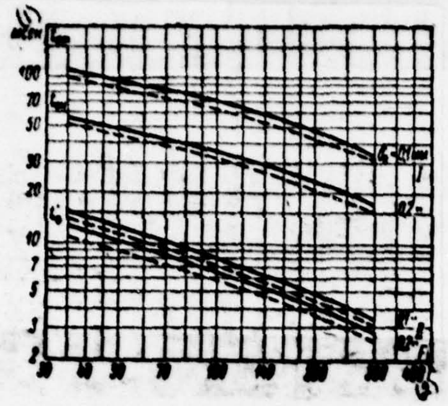

Fig. 11-10. Curved of releasing time of relay of type RKM-1 ($C_н$ = 5,4·10⁻⁶ ohm); solid lines are circuit closing contacts; broken - breaking contact. I - release/tempering with the shorting of winding; II - release/tempering with the disconnection of winding.

Key: (1). ms. (2). g.

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Figures 11-11 shows the curves of the dependences of the releasing time of normal (h = 0) and the deferred-action (h = 1 and h = 2 mm) relays of type RKM-1 on the magnetizing ampere-turns at load by three contact groups on switching and the height/altitude of the plug of loosening 0.1 mm.

d) Relays of the type RES14.

Figures 11-12, 11-13 give the tentative curves of releasing time normal and deferred-action ($h_{нз} = 3$ мм; $C_{нз} = 3{,}56 \cdot 10^{-6}$ ohm) by relay of the type RES14.

e) Relays of the type RKMP.

Figures 11-14, 11-15 show tentative curves to releasing time normal and deferred-action ($h_{нз} = 4$ мм; $C_{нз} = 4{,}95 \cdot 10^{-6}$ ohm) relay of the type RKMP.

f) Relays of the type RMU.

The curves of the dependences of the releasing time of relay of the type RMU on the load of armature with

AW =
= 600 AV and $\delta_0$ = 0 are given in Fig. 11-16 ($C_н = 11,4 \cdot 10^{-6}$ ohm). Figures 11-17 gives the curves of the dependences of releasing time on the magnetizing ampere-turns with shorting (I) and disconnection (II) of the winding of relay of the type RMU, loaded four by stud switches.

g) The relays of types RS-52 and RS-13.

Figures 11-18 gives the curves of the dependences of releasing time on the load of armature for the relay of types RS-52 ($\delta_0$ = 0 and $C_н = 9,06 \cdot 10^{-6}$ ohm) and RS-13 ($\delta_0$ = 0.1 mm and $C_н = 10,2 \cdot 10^{-6}$ ohm).

Table 11-3. Loads of the retention of relay of type RKM-1.

| (1) Обозначение групп | (2) Нагрузка удержания $F_y$, Г |
|---|---|
| (3) Якорь | 30 |
| а | 35 |
| г | 28 |
| и | 40 |
| аа | 65 |
| гг | 54 |
| аг | 60 |
| ги | 63 |
| иа | 68 |

Key: (1). Designation of groups. (2). Load of retention $F_y$ g. (3). Armature.

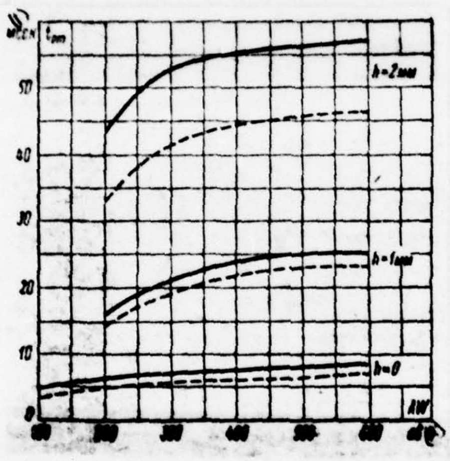


Fig. 11-11. Curved of dependences of releasing time of relay of type RKM-1 on magnetizing ampere-turns (load is 3 groups to switching, plug - 0.1 mm).

Key: (1). ms. (2). AV.

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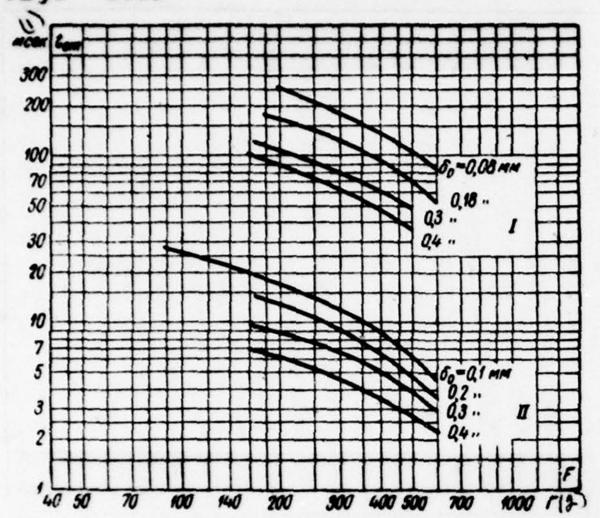


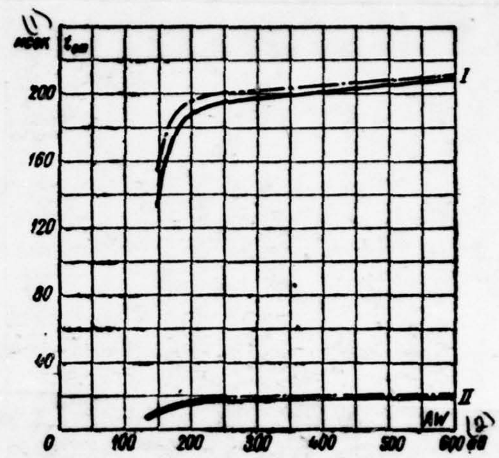


Fig. 11-13.

Fig. 11-12. Curved of releasing time of relay of type RES14. I - time-lag relay (h = 3 mm); II - normal relay.

Key: (1). ms. (2). g.

Fig. 11-13. Curved of dependences of releasing time of relay of type RES14 on ampere-turns (load - switching contacts; $\delta_0$ = 0.08 mm). I - retarded; II - normal relay.

Key: (1). ms. (2). AV.

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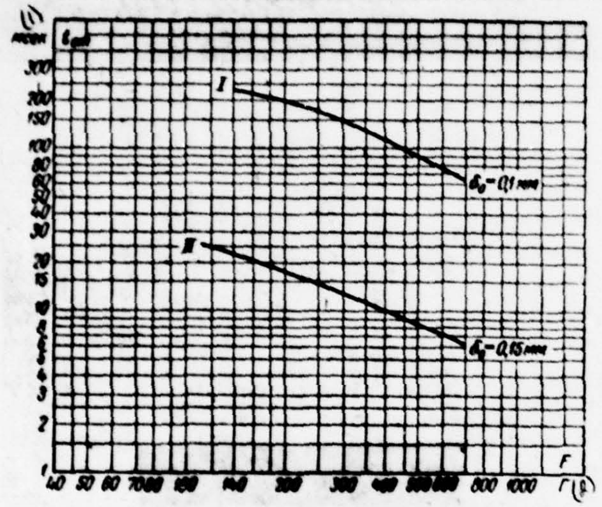


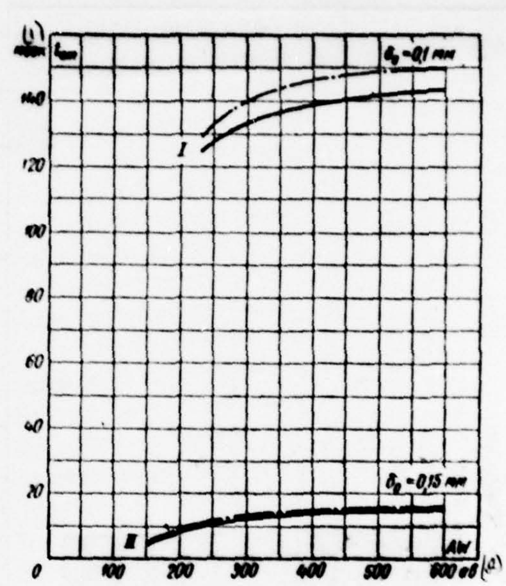


Fig. 11-15.

Fig. 11-14. Curved of releasing time of relay of type RKMP. I - time-lag relay, h = 4 mm; II - normal relay.

Key: (1). ms. (2). g.

Fig. 11-15. Curved of dependences of releasing time of relay of type RKMP on ampere-turns (lcad is 2 stud switches). I - time-lag relay, h = 4 mm; II - normal relay.

Key: (1). ms. (2). AV.

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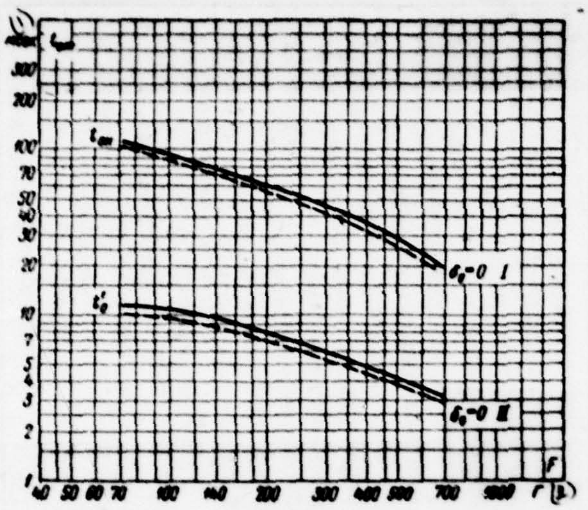

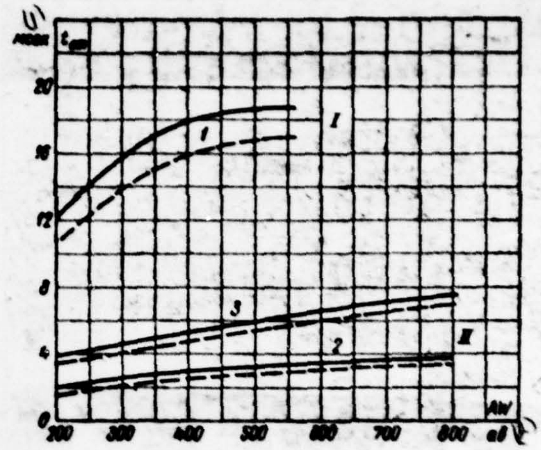
Fig. 11-17.

Fig. 11-16. Curved of releasing time of relay of type RMU ($C_{м}$ = 11,4·10⁻⁴ ohm). I - release/tempering with the shorting of winding; II - release/tempering with the disconnection of winding.

Key: (1). ms. (2). g.

Fig. 11-17. Curved of dependences of releasing time of relay of type RMU on magnetizing ampere turns. 1, 2 - load 4 stud switches; 3 - load 2 stud switches.

Key: (1). ms. (2). AV.

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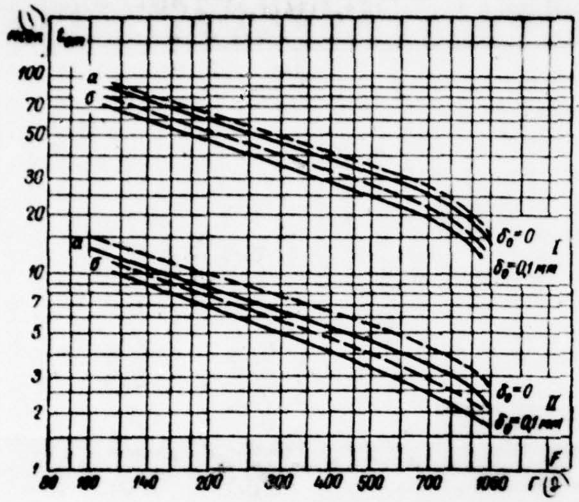


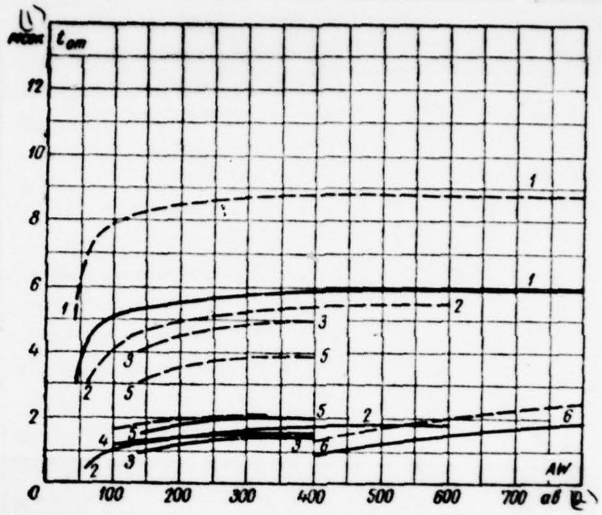


Fig. 11-19.

Fig. 11-18. Curved of releasing time of relay of types RS-52 and RS-13: a - relay of type RS-52 ($C_н = 9{,}06\cdot10^{-6}$ ohm); b - relay of type RS-13 ($C_н = 10{,}2\cdot10^{-6}$ ohm). I - release/tempering with the shorting of winding; II - release with the disconnection of winding.

Key: (1). ms. (2). g.

Fig. 11-19. Curved of dependences of releasing time on magnetizing ampere-turns. 1 - relay of the type RDCG ($\delta_0$ = 0.1 mm; F = 60 g): 2 - relay of the type RDCG ($\delta_0$ = 0.3 mm; F = 30 g): 3 - relay of the type RES9; 4 - relay of the type RES10; 5 - relay of the type RES6; 6 - relay of the type RS-52 with two stud switches.

Key: (1). ms. (2). AV.

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h) The relays of types RES6, RES9, RES10 and RDCG.

Tentative the curves of the dependences of releasing time on the magnetizing ampere-turns for the relay of types RES6, RES9, RES10, RDCG and RS-52 are given in Fig. 11-19.

The loads of release/tempering for the fundamental contact groups of the relay of the type RES14 and of the types RKMP, RMU, RS-52 and RS-13 are given in Table 5-14 and 5-15.

11-10. Empirical formulas for timing release of relay.

From Fig. 11-5, 11-7, 11-8 and 11-10 it follows that

the curves of the dependences of the releasing time of relay on the load of armature F on logarithmic scale are on working sections (approximately from 40-70 to 200-300 g) virtually straight lines. Consequently, the dependence of the releasing time of relay on the load of armature on the straight portion of each curve can be approximated by the formula of the following form:

$$t_{\text{от}} = t_{0F1} F^{\alpha},$$

where $t_{0F1}$ is a releasing time which would have relay with this height/altitude of plug and the load of armature in 1 kgf, if curve remained rectilinear to load in 1 kgf, F - load of armature in kgf and $\alpha$ - a slope tangent of this straight line to the axis of abscissas.

The value of the exponent $\alpha$ of normal relays varies usually within limits from 0.62 to 0.78, and of time-lag relay - approximately from 0.55 to 0.73.

The value of quantity $t_{0F1}$ for a normal relay of the type RKN at the height/altitude of plug 0.1 mm ($\delta_0$ = 0.1 mm) is equal to 17 ms and $\alpha$ = 0.73 or 20.5 ms with $\alpha$ = 0.667, for the deferred-action (by means of the shorting of winding) relay $t_{0F_1} = 120$ ms and $\alpha$ = 0.73 or $t_{0F1} = 140$ ms with $\alpha$ = 0.667.

Consequently, the releasing time of a normal relay of the type RKN at the height/altitude of the plug of loosening $\delta_0$ = 0.1 mm can be expressed by the following formula:

$$t_0' = 17F^{-0.73} \approx 20{,}5F^{-0{,}67} = \frac{20{,}5}{\sqrt[3]{F^2}} \quad [\text{ms}],$$

and the releasing time of relay of the type RKN with $\delta_0$ = 0.1 mm and shorting of its winding $(C_{\text{н}} = 3{,}2 \cdot 10^{-6}$ ohm) will be equal to:

$$t_{0\text{н}} = 120F^{-0{,}73} \approx \frac{140}{\sqrt[3]{F^2}} \quad [\text{ms}].$$

In Fig. 11-20 are constructed dependence curves of values $t_{0F1}$ for a normal relay of the type RKN at break and shorting of its winding from the height/altitude of the plug of loosening.

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These curves within the altitude limits of the plug of loosening from 0.1 to 0.3 mm are rectilinear and can be

expressed by the following formulas:

for a normal relay of type RKN during disconnection (line break) of the winding circuit

$$t'_{oF1} = t'_{o\delta 1}\delta_o^{-\beta} = 5\delta_o^{-0.64} \approx \frac{4.8}{\sqrt[3]{\delta_o^2}}$$

and with the shorting of its winding with $C_{n} = 3.2 \cdot 10^{-6}$ ohm

$$t_{oF1} = 41\delta_o^{-0.59} \approx \frac{35}{\sqrt[3]{\delta_o^2}}.$$

Thus, the releasing time of a normal relay of the type RKN can be determined by the following approximation formulas:

during interrupting of the circuit of the winding of the relay

$$t'_o = \frac{t'_{o\delta 1}}{\sqrt[3]{F^2\delta_o^2}} \approx \frac{4.8}{\sqrt[3]{F^2\delta_o^2}}; \qquad (11\text{-}39a)$$

with the shorting of the winding, which fills whole winding space of coil ($C_{n}^{*} = 3.2 \cdot 10^{-6}$ ohm),

$$t_{on} = \frac{t_{o\delta 1}}{\sqrt[3]{F^2\delta_o^2}} \approx \frac{35}{\sqrt[3]{F^2\delta_o^2}}. \qquad (11\text{-}39b)$$

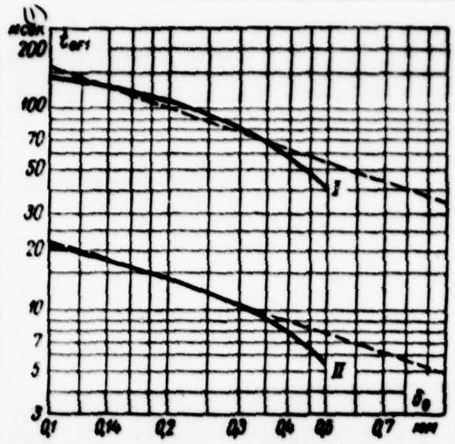


Fig. 11-20. Dependence curves of value $t_{oF_1}$ for relay of type RKN from height/altitude of type of loosening. I - with the shorting of winding; II - with the disconnection of winding.

Key: (1). ms.

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In these formulas t - time in ms, F - the load of armature in kgf and $\delta_0$ - the height/altitude of plug in mm.

The investigations of author will show that the releasing time of valve type relay with the pole pieces within the limits of the weight of steel of the magnetic circuit of these relays from 0.005 to 0.1 kg (weight of relay with it is measured from 0.012 to 0.25 kg) it can be expressed following approximation formulas:

during interrupting of the circuit of the winding of the relay:

$$t_{o}' \approx \frac{30Q_c}{\sqrt[4]{F^2\delta_3^3}}; \qquad (11\text{-}40a)$$

with the shorting of the winding

$$t_{o\text{ш}} \approx \frac{1200\sqrt{Q_c^3}}{\sqrt[3]{F^2\delta_3^2}}, \qquad (11\text{-}40b)$$

where $Q_c$ is weight of steel of the magnetic circuit of relay in kg.

These formulas are valid within the limits of changes in the load of armature from 0.07 to 0.4 kgf and the height/altitude of the plug of loosening from 0.1 to 0.3 mm.

For the relay of large overall sizes by weight approximately from 0.25 to 2.5 kg the releasing time can be determined by the formulas:

during interrupting of the circuit of the winding of the relay

$$t_о' \approx \frac{40 Q_c}{\sqrt[3]{F^2}\sqrt[4]{\delta_0^3}}; \qquad (11\text{-}40c)$$

with the shorting of the winding, which fills whole winding space of the coil

$$t_{он} \approx \frac{800\sqrt{Q_c^3}}{\sqrt[3]{F^2}\sqrt[4]{\delta_0^3}}. \qquad (11\text{-}40d)$$

For relay by weight from 0.08 to 0.5 kg, which do not have the pole pieces, releasing time during interrupting of the circuit of the winding

$$t_о' \approx \frac{57\sqrt{Q_c^3}}{\sqrt[3]{F^2\delta_0^2}} \qquad (11\text{-}40e)$$

and with the shorting of the winding, which fills whole winding space of coil,

$$t_{он} \approx \frac{620\sqrt{Q_c^3}}{\sqrt[3]{F^2\delta_0^2}}. \qquad (11\text{-}40f)$$

11-11. Releasing time of relay during pulsed mode.

During pulsed mode, the coil current of relay usually does not manage grow to conservative value, in consequence of which the releasing time of pulse of relay it depends on the duration of the momentum/impulse/pulse of exciting current.

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Therefore curves for timing of the release/tempering of relay (Fig. 11-21), taken during "static" conditions/mode work, cannot be used for the calculation of series and pulse relays.

If the value of inductance is is considered constant, not depending on current, then for the magnetizing ampere-turns it is possible to write the following expression:

$$AW = AW_{yc}(1 - e^{-\frac{t_1}{\tau}}), \qquad (11\text{-}41)$$

where $AW_{yc}$ is conservative value of the magnetizing ampere turns, $t_1$ - the duration of the magnetizing momentum/impulse/pulse (duration of connection/inclusion) and $\tau$ - the time constant of relay circuit.

In the case of the series connection of effective resistance $r_d$ time constant

$$\tau = \frac{L}{R + r_d}.$$

If relay has quadrature winding, then time constant

$$\tau = \frac{L}{R + r_d} + \frac{L_K}{R_K}.$$

From formula (11-41) it follows that if $t_1$ it is less than 3 $\tau$, then the magnetizing ampere-turns will differ from those who were being steady more than in 5o/o. Knowing the duration of the magnetizing pulse and the constant value of the time of relay circuit, it is possible with the aid of (11-41) to calculate the appropriate magnetizing ampere turns, also, according to curve, given in Fig. 11-21, to determine the releasing time of our relay.

However, virtually the inductance of relay depends on the current strength; furthermore, because of eddy-current effect the value of magnetic flux (at just one value of the magnetizing ampere-turns) in the case of pulsed mode will be less than at the "static" operating mode. Therefore for determining the releasing time of relays of type 100, operating in pulsed operation, Fig. 11-22 gives the curves of the dependences of the releasing time of relay on the value of the supplementary resistor/resistance $r_d$, connected serially, at the different duration of igniting pulses.

These curves were taken both during the interrupting and with the shorting of the winding of relay. The load of relay is 2 and 5 contact springs; winding impedance of relay 330 ohm; turn number 10000; the height/altitude of the plug of armature 0.2 mm; $AW_{ye} = 600$ ampere-turns.

From curves, given in Fig. 11-22, it follows that the minimum value $r_d$, at which the time of release reaches conservative value, depends on the duration of the magnetizing pulse.

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For the duration of this pulse in 20 ms, the releasing time of relay reaches conservative value with $r_d \approx 1400$ ohm. For the pulse duration in 30 ms, value $r_d$ decreases to 800 ohm, while for duration in 50 ms, the releasing time of relay does not in practice depend on value $r_d$. The character of these dependences is retained with the different loads of relay.

Figure 11-23 gives for this same a relay the curves of the dependences of releasing time on conservative value of the magnetizing ampere-turns for a different duration of the magnetizing pulses and with a constant value $r_d = 600$ ohm.

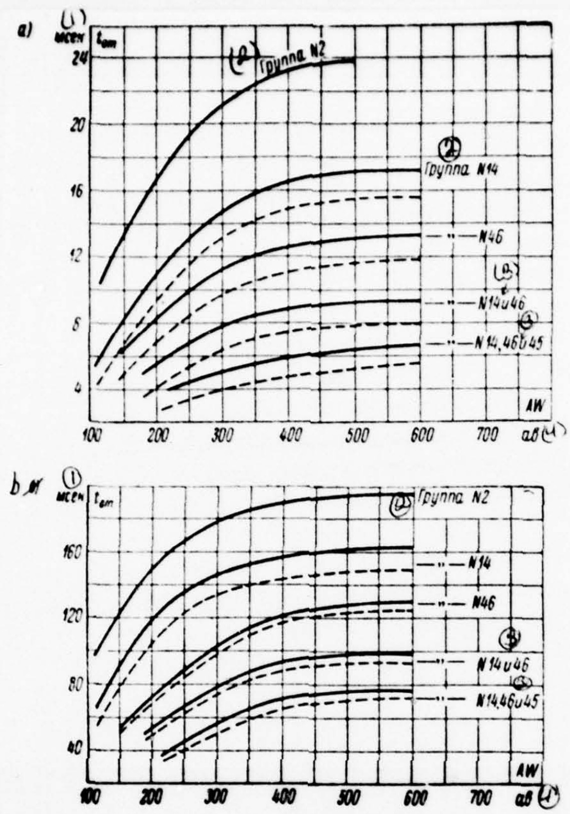


Fig. 11-21. Curved of dependences of releasing time of relay of type 100 on ampere-turns: a - release/tempering with disconnection of winding; b - release/tempering with shorting of winding ($C_{н} = 3{,}3 \cdot 10^{-6}$ ohm), plug 0.2 mm; solid lines are breaking contact; broken - circuit closing contacts.

Key: (1). ms. (2). Group. (3). and. (4). AV.

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The curves of the dependences of releasing time on conservative value of magnetizing ampere-turns with different value $r_d$ are given in Fig. 11-24.

These curves show that for the duration of the magnetizing momentum/impulse/pulse 30 ms and $r_d = 120$ ohm the releasing time of relay reaches conservative value with 600 ampere-turns.

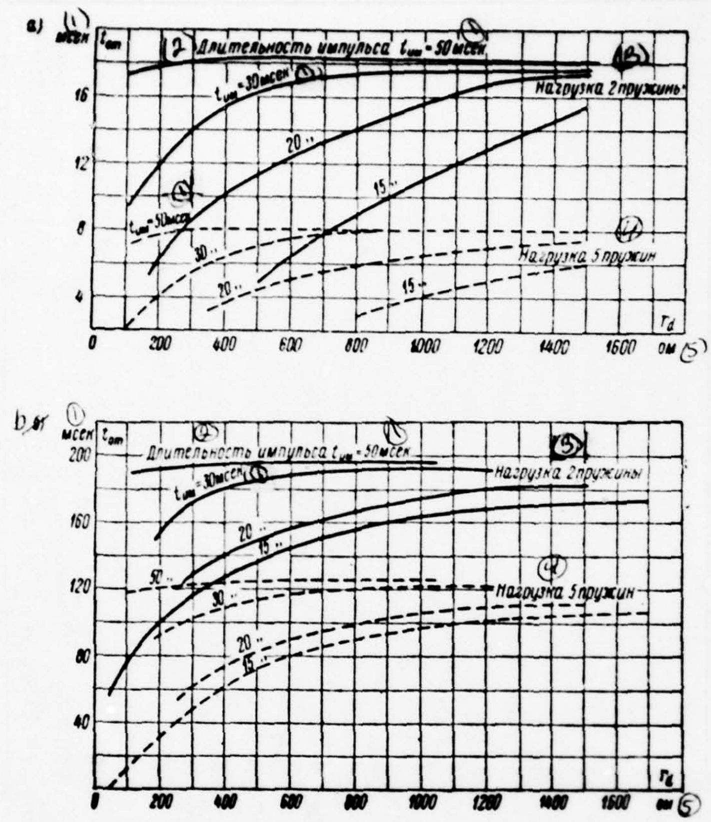


Fig. 11-22. Curved of dependences of releasing time of relay of type 100 on value of supplementary resistor/resistance at different duration of magnetizing pulses: a - release/tempering with disconnection of winding; b - release/tempering with shorting of winding.

Key: (1). ms. (2). Pulse duration. (3). the load 2 of spring. (4). Load 5 of springs. (5). ohm.

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If we accept the inductance of relay with 600 ampere-turns of the equal to 13 H, then time constant with $r_d = 1200$ ohm will be equal to:

$$\tau = \frac{L}{R + r_d} = \frac{13}{330 + 1200} = 0{,}0085 \text{ сек}^{(1)} = 8{,}5 \text{ мсек}^{(2)}.$$

Key: (1). s. (2). ms.

Consequently, so that the releasing time differs from conservative value less than for 5o/o, the pulse duration must be more 3•8.5 = 25.5 ms. Thus, with the momentum/impulse/pulses of average duration calculation data approach results of the experimental check of releasing time.

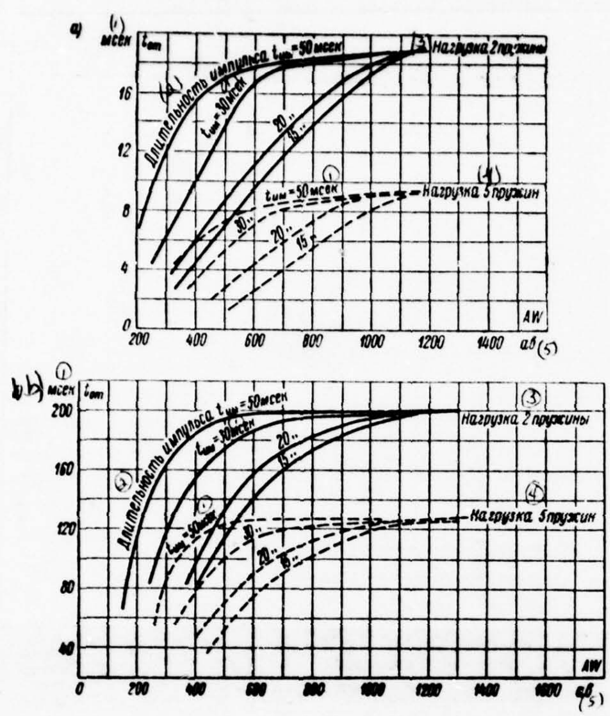


Fig. 11-23. Curved of dependences of releasing time of relay of type 100 on magnetizing ampere-turns during pulsed mode: a) release/tempering with disconnection of winding; b) release/tempering with shorting of winding.

Key: (1). ms. (2). Duration of momentum/impulse/pulse $t_{им} = 50$ ms. (3). Load of 2 springs. (4). Load of 5 springs. (5). ampere-turns.

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For determining the releasing time normal and time-lags relay of type 100, of the workers in pulsed operation, Fig. 11-25 and 11-26 shows curves dependences of the releasing time of these relays from the load of armature for the different duration of the magnetizing pulses.

These curves were taken with the values of plugs 0.1 and 0.2 mm and $AW_{yo} = 600$ to ampere-turns.

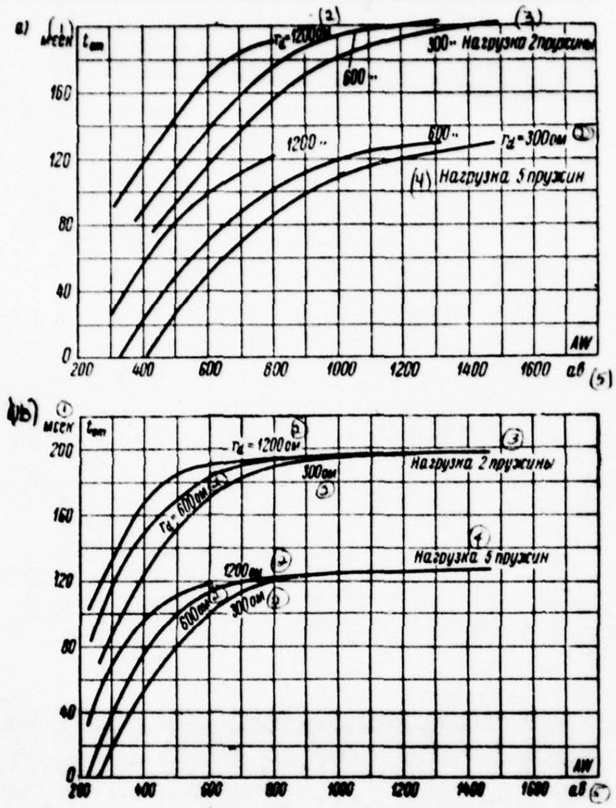


Fig. 11-24. Curved of dependences of time of release of relay of type 100 on ampere-turns with different value of supplementary resistor/resistance and shorting of winding: a) duration of magnetizing momentum/impulse/pulses 15 ms; b) duration of magnetizing momentum/impulse/pulses 30 ms.

Key: (1). ms. (2). ohm. (3). Load of 2 springs. (4). Load of 5 springs. (5). ampere-turns.

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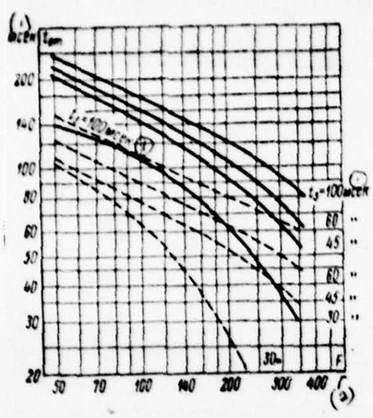

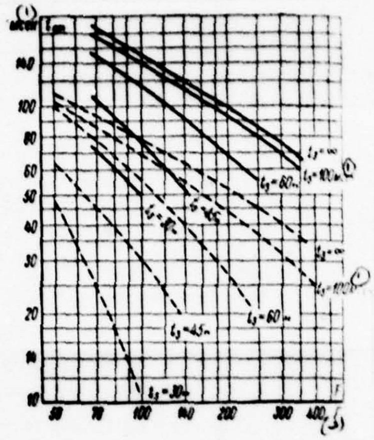

Fig. 11-25. Curved of releasing time of normal relay of type 100 with shorting of winding and different duration of magnetizing pulses.

Key: (1). ms. (2). g.

Fig. 11-26. Curved of time of release of time-lag relay of type 100 with disconnection of winding and different duration of magnetizing pulses.

Key: (1). ms. (2). g.

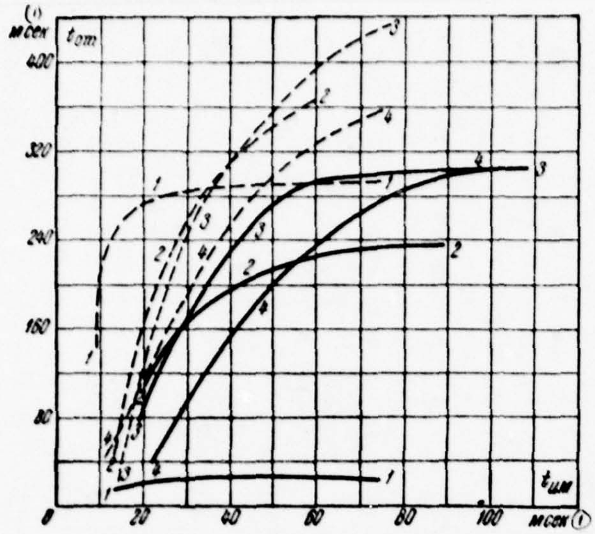


Fig. 11-27. Curved of dependences of releasing time of relay of type 100 on duration of magnetizing pulses. 1 - $C_H$ = normal relay; 2 - time-lag relay, the tube Ф 12/8 mm ($C_H$ = 4.46·10⁻⁶ = $4.46 \cdot 10^{-6}$ ohm): 3 - time-lag relay, the tube Ф 14/8 with mm ($C_H$ = 6.63 × × $10^{-6}$ ohm): 4 - deferred-action to release/tempering relay, plug by length 38 mm ($C_H$ = $7.12 \cdot 10^{-6}$ ohm).

Key: (1). ms.

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For the comparison between themselves of the releasing

time of normal and time-lag relay of type 100, of the workers in pulsed operation, Fig. 11-27 gives the curves of the dependences of the releasing time of these relays on the duration of the magnetizing pulses at constant values $AW_{yc} = 600$ ampere-turns and $r_d = 600$ ohm.

All relay have identical turn number: 10,000; winding impedance of normal relay it is equal to 310 ohm, time-lags relay with the tubes 563 ohm and deferred-action for release/tempering (with plug) 712 ohm.

Each relay loaded by one contact group No 14 (switching with interrupting before closing/shorting) and was regulated normally. Course of armature 0.7 mm, plug 0.11 mm pressure in the contacts 25 g.

From the curves of Fig. 11-27, it follows that the releasing time of normal relays with the shorting of winding considerably less depends on the duration of the magnetizing pulses, than time-lags relay.

For a normal relay the releasing time does not virtually change for the duration of the magnetizing pulse of more than 20 ms. During a decrease in the pulse

duration, the releasing time of relay sharply decreases.

The releasing time of time-lags relay begins noticeably to decrease with the duration of the magnetizing pulse of less 80-100 ms. This is explained to the fact that the rate of the growth/build-up of the magnetic flux of normal relay is considerably more than retarded.

If the duration of the magnetizing pulse is equal to 30 ms, then with $AW_{yc} = 600$ ampere-turns and $r_d = 600$ ohm the releasing time of the relay, retarded for release/tempering (with plug), will be equal to 92 ms, the deferred-action with red copper tube - 164 s and normal relay with the shorting of winding - 280 ms.

Thus, as series relay to favorably apply instead of the deferred-action normal relay whose winding is shoun circuit after function.

11-12. Effect of capacitance/capacity on the releasing time of relay.

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For an increase in the releasing time in parallel to the winding of relay sometimes is included the capacitance/capacity (Fig. 11-28).

In this case for the limitation of rate of charge, passing through contacts during closing a circuit, and also for an increase in the attenuation of the oscillatory circuit consecutively with condenser/capacitor usually is included the resistor/resistance $r_c$.

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At the disconnection of circuit, the value of the current, passing through the winding of relay, as is known, is expressed by the following formula:

$$i = Ie^{-bt}\left(\mathrm{ch}\,\omega_0 t - \frac{b_0 - a_0}{\omega_0}\,\mathrm{sh}\,\omega_0 t\right). \qquad (11\text{-}42)$$

where

$$\omega_0 = \sqrt{b^2 - a^2}, \quad b = \frac{R + r_c}{2L}, \quad a^2 = \frac{1}{LC_{\kappa}} \overset{(1)}{\text{и}}\ a_0 = \frac{R}{L}.$$

**Key: (1). and.**

The aperiodic discharge of condenser/capacitor will occur in the case when

$$(R + r_c) > 2\sqrt{\frac{L}{C_{\kappa}}}.$$

For relay of the type RKN with the actuation voltage

and $r_c$, equal to zero, for obtaining the aperiodic process it is necessary that value $n_1 = C_к w^2$ will be more 800•10² (at the dual reserve $n_1$ must be more 200•10²).

The dependence of releasing time on the load of armature increases with a decrease in coefficient of $n_1$ and it reaches maximum in the absence of condenser/capacitor.

High speed telephone and telegraph relays have a time constant less than 0.01 s; in this case during aperiodic process, when $(R + r_c) \geq 10\sqrt{\frac{L}{C_к}}$, it is possible to disregard the inductance of winding [10-22], and for a coil current of relay with the disconnection of supply network to write the following equation:

$$i = \frac{U}{R_1} e^{-\frac{t}{R_1 C_к}}, \qquad (11\text{-}43)$$

where $R_1 = R + r_c$ is the total resistance of the discharge circuit of condenser/capacitor.

Hence time for motion to start with the release/tempering of relay will be equal to:

$$t_{от} = C_к R_1 \ln \frac{U}{I_{от} R_1}. \qquad (11\text{-}44)$$

With an increase in the resistor/resistance of relay circuit, the time constant increases, and the constant of action decreases.

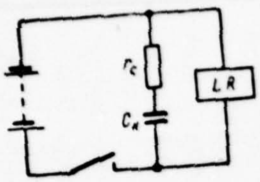


Fig. 11-28. Circuit diagram of capacitance/capacity and resistor/resistance in parallel to winding of relay.

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For determining the condition by which the releasing time of relay in this conditions/mode will be maximum, let us differentiate of $t_{от}$ in terms of $R_1$ and will equate it with zero; we will obtain:

$$\frac{dt_{от}}{dR_1} = -C_к + C_к \ln\frac{U}{I_{от}R_1} = 0 \overset{(1)}{\text{или}} \ln\frac{U}{I_{от}R_1} = 1,$$

Key: (1). or.

whence we find the optimum value of the resistor/resistance of circuit the discharging of the condenser/capacitor:

$$R_{опт} = \frac{U}{eI_{от}} = 0{,}368\,\frac{U}{I_{от}}. \qquad (11\text{-}45)$$

The maximum value of the time for motion to start of relay with release/tempering in the assigned conditions/mode,

obviously, will be equal to:

$$t_{\text{макс}} = R_{\text{опт}} C_{\text{к}} = 0{,}368 C_{\text{к}} \frac{U}{I_{\text{от}}} = 0{,}368\, C_{\text{к}} R \frac{K_1}{k_{\text{в}}}. \quad (11\text{-}46)$$

Figures 11-29 gives the curves of the dependences of the releasing time of relay of the type RKN on the value of the total resistance of the discharge circuit of condenser/capacitor at different voltages.

Capacitance of capacitor is equal to 100 μF. The winding of relay has 12,300 turns, resistor/resistance 610 ohm. Value of the spill current 8 mA, of the current of release/tempering 2 mA.

From these curves it follows that with small voltages the releasing time of relay with an increase in the resistor/resistance does not increase. With high voltages the releasing time of relay has clearly expressed maximum.

The releasing time of relay with a change in the stress from 5 to 100 V when $r_c$, the equal to zero, increases in all 1.9 times, and with the optimum value of resistor/resistance - 14 times.

The value of optimum resistor/resistance increases with an increase in the voltage of battery.

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A change of the value of optimum resistor/resistance within limits of $\pm$30-40o/o barely affects the releasing time of relay; therefore for optimum resistor/resistance it is possible to write the following equation:

$$R + r_c = (0{,}27 \div 0{,}50)\frac{U}{I_{or}}. \qquad (11\text{-}45a)$$

Capacitance of capacitor (in farads), according to equation (10-55), can be expressed by the formula:

$$C_K = \frac{n_1}{w^2}.$$

Load voltage of circuit is equal to:

$$U = IR = I_c K_1 C w^2 = AW_c K_1 C w,$$

where $K_1$ is an actual safety factor on current (or voltage) and $C = R/w^2$.

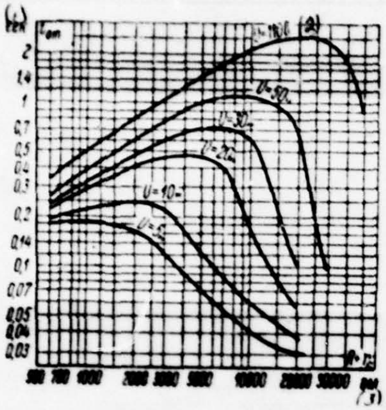

Fig. 11-29. Curved of dependences of releasing time of relay of type RKN on value of resistor/resistance $R+r_c$.

Key: (1). s. (2). V. (3). ohm.

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If consecutively with the winding of relay is included resistor/resistance $r_p$, then $C=\frac{R+r_p}{w^2}$. The value of the current of release/tempering can be expressed as follows:

$$I_{от}=\frac{AW_{от}}{w}.$$

Substituting in equation (11-46) instead of U and $I_{от}$ their values, we obtain for the greatest time for motion to start with release/tempering (in s):

$$t_{от.\,макс}=0{,}368C_{к}K_1Cw^2\frac{AW_c}{AW_{от}}=0{,}368\,C_{к}Cw^2\frac{K_1}{k_в}. \quad (11\text{-}47)$$

where $k_{\text{в}}$ - the relay reset coefficient, equal to $\frac{AW_{\text{от}}}{AW_{\text{c}}}$.

Consequently, the optimum releasing time of relay is proportional to capacitance of capacitor, to the square of the turn number of the winding of relay, to the resistor/resistance of one turn and it is inversely proportional to the relay reset coefficient. With a constant value of the applied voltage, the releasing time is proportional to capacitance of capacitor and to the turn number of the winding of relay.

Formula (11-47) does not consider eddy-current effect and time of the motion of armature; furthermore, it gives the sufficiently accurate results in the case when $(R+r_{\text{c}})\geqslant 10\cdot\sqrt{\frac{L}{C_{\text{к}}}}$. Therefore for determining the releasing time of standard relays, are most convenient used curves, obtained experimentally.

Figures 11-30 gives the curves of the dependences of the greatest releasing time of relay of the type RKN on the value of relation $\frac{C_{\text{к}}w^2}{k_{\text{в}}}$ at the different values of factor $K_1$C.

Analyzing the given above curves, it is easy to note

that the right sides of these curves are the virtually direct/straight parallel lines, distant from each other at the distances, proportional to the value of factor $K_1C$. Furthermore, curved with identical values $K_1C$ of different types relays differ little from each other.

For obtaining the generalized graphic calculated materials, were constructed the series of the curves of the dependence of maximum releasing time on value $C_{\text{н}}R\frac{K_1}{k_{\text{н}}}$ for the relay of types RPN, RKN, RKM-1, RS-13 and MKU-48. Moreover it turned out that the right sides of these series of curves of each type of relay are virtually poured into one line, and left diverge to different values.

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This disagreement between at times of the release/tempering of relay at the different values of factor $K_1C$ increases with a decrease in value $C_{\text{н}}R\frac{K_1}{k_{\text{н}}}$. Therefore for each type of relay, were calculated average curves of dependence of releasing time from value $C_{\text{н}}R\frac{K_1}{k_{\text{н}}}$ and were determined the percentages of the deviation of releasing time at the different points of separate curves from the appropriate points of average curve.

Figures 11-31 gives average the curves of the dependences of the greatest releasing time on value $C_{н}R\frac{K_1}{k_{н}}$ for the relay of types RPN, RKN, RKM-1, RS-13, MKU-48. For a comparison by dotted line is shown theoretical curve (6), constructed according to formula (11-47).

From figure it follows that the average value of the greatest releasing time for the different types of relay at the large values of quantity $C_{н}R\frac{K_1}{k_{н}}$ coincides, but with small it differs not more than by ±10o/o.

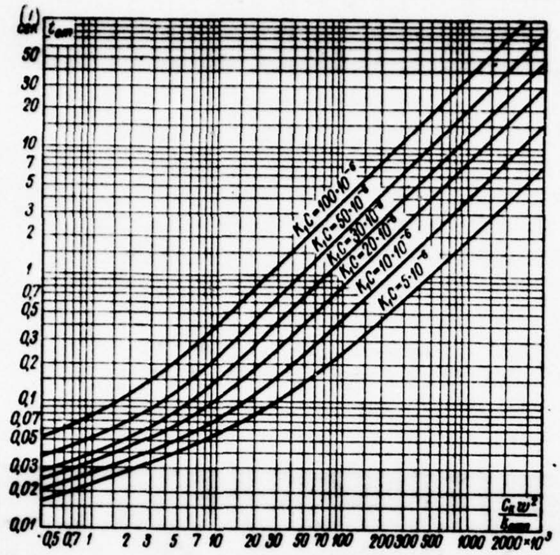


Fig. 11-30. Curved of greatest releasing time of relay of type RKN.

Key: (1). s.

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Therefore the curves of Fig. 11-31 it is possible to use for the tentative timing of the release/tempering of any analogous types of valve type relay.

Analogous timing of release/tempering according to

formula (11-47) gives usually smaller values, especially at the low values of quantity $C_{\kappa}R\frac{K_1}{k_{\text{в}}}$, therefore to use this formula is possible only, if $C_{\kappa}R\frac{K_1}{k_{\text{в}}}>5$.

Figures 11-32 gives average the curves of the probable deviation of the releasing time of relay of any type in percentages from the average value of this time in dependence from value $C_{\kappa}R\frac{K_1}{k_{\text{в}}}$. These curves are constructed separately for increase (+) and a decrease (-) releasing time they are average for all types enumerated above of relays.

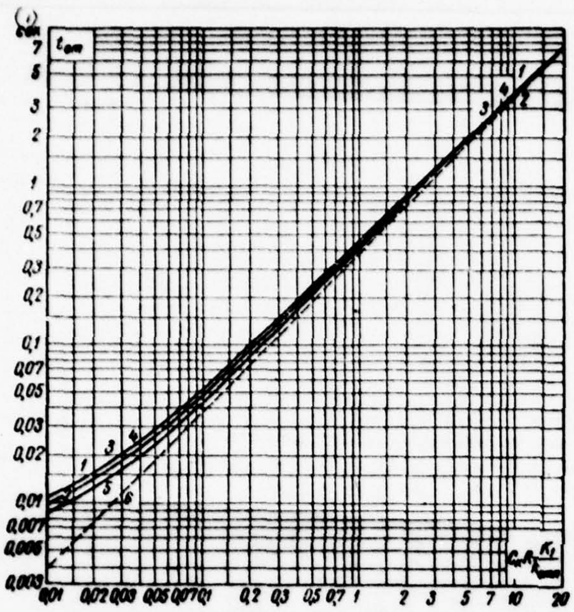


Fig. 11-31. Average curves of greatest releasing time of relay. 1 - type RPN; 2 - type RKN; 3 - type RKM-1; 4 - type RS-13; 5 - type MKU-48; 6 - theoretical curve.

Key: (1). s.

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By dotted lines Fig. 11-32 shows the maximum significance of a deviation of releasing time in percentages, which were being observed at separate values

$K_1C$ of some types of relay. From these curves follows that with values $C_{\text{н}}R\frac{K_1}{k_{\text{в}}}>0,3$ the possible mean deviation of the releasing time of relay from average value will not exceed ±8o/o, but maximum deviation of 14o/o.

It is necessary to consider that the curves of Fig. 11-30 and 11-31 are constructed for a maximum releasing time for obtaining which in the circuit of condenser/capacitor it is necessary to include/connect the optimum resistor/resistance, determined with the aid of formula (11-45a).

If relay has low resistor/resistance, then for the limitation of circuital current consecutively with winding can be included resistor/resistance $r_p$. The value of this resistor/resistance $r_p$ one should select in such a way as to ensure a sufficient reserve on the current (voltage) of function (not less than 1.7-2.0).

Consecutively with condenser/capacitor in this case, obviously, one should include/connect the resistor/resistance

$$r_c = (0,27 \div 0,50)\frac{U}{I_c} - (R + r_p). \qquad (11\text{-}49)$$

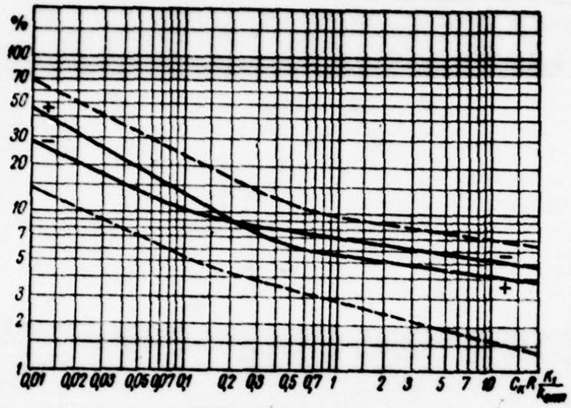


**Fig. 11-32. Average curves of probable deviation of releasing time of relay (in percentages) from average value.**

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11-13. Effect of varistor on the releasing time of relay.

Upon the connection/inclusion of varistor in parallel to the winding of relay for spark extinguishing the releasing time of relay increases.

For the case of the disconnection (break) of the circuit of the winding of relay, shunted by varistor, if

we disregard eddy-current effect, it is possible to write, taking into account (19-22), the following equation:

$$iR + L\frac{di}{dt} + u_0 i^{\beta} = 0, \qquad (11\text{-}50)$$

where $u_0$ - it is constant of varistor and $\beta$ - the coefficient, equal the control ratio of varistor (on logarithmic scale) to the axis of abscissas.

Let us divide all terms of equation (11-50) on $Li^{\beta}$ and, designating $i_1 = i^{1-\beta}$, after simple conversions we have:

$$\frac{di_1}{Ri_1 + u_0} = -\frac{1-\beta}{L}dt. \qquad (11\text{-}51)$$

Integrating last/latter equation, we obtain after replacement $i_1$ by $i^{1-\beta}$ the following expression:

$$Ri^{1-\beta} + u_0 = c_1 e^{-\frac{R}{L}(1-\beta)t}.$$

Integration constant we find from initial conditions: with t = 0

$$i = I_H \overset{(1)}{} \; c_1 = RI^{1-\beta} + u_0.$$

Key: (1). and.

Then

$$Ri^{1-\beta} + u_0 = (RI^{1-\beta} + u_0)e^{-\frac{R}{L}(1-\beta)t}$$

or

$$i = \left[\left(I^{1-\beta} + \frac{u_0}{R}\right)e^{-\frac{R}{L}(1-\beta)t} - \frac{u_0}{R}\right]^{\frac{1}{1-\beta}}. \qquad (11\text{-}52)$$

From (11-52) we find time for motion to start with the release/tempering of relay, with which the coil current

decreases to the value of the current of the release/tempering:

$$t_{\text{от}} = \frac{L}{R(1-\beta)} \ln \frac{RI^{1-\beta} + u_0}{RI_{\text{от}}^{1-\beta} + u_0}.$$

At the moment of interrupting contacts, the voltage on varistor $U_1$ is equal to $u_0 I^{\beta}$. Designating the ratio of conservative value of current to the current of release/tempering through $k = I/I_{\text{от}}$, we obtain:

$$t_{\text{от}} = \frac{L}{R(1-\beta)} \ln \frac{U + U_1}{U k^{\beta - 1} + U_1}, \qquad (11\text{-}53)$$

where U - supply voltage (battery).

This formula does not consider eddy-current effect, saturation of steel of magnetic circuit and time of the motion of armature.

The value of coefficient $\beta$ is usually equal to 0.3, load voltage of contacts $U_1$ + U must not exceed $U_{\text{пр}}$; therefore

$$t_{\text{от}} \approx \frac{L}{0{,}7R} \ln \frac{U_{\text{пр}}}{U_{\text{пр}} + U(k^{-0.7} - 1)}. \qquad (11\text{-}53a)$$

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11-14. Examples.

1. Let us determine time constant of decrease of magnetic flux of relay of type RKN (without pole piece) during interrupting of circuit of winding.

Relay has a core as a radius 0.45 cm and as length 7 cm. Section of housing 2.06 x 0.4 $cm^2$, length 8.5 cm. Height/altitude of the plug of loosening 0.02 cm, $\rho_1$ = 10.5 × $10^{-8}$ Ω•m.

It is obvious, the time constant of the decrease of the flow of relay is composed of the time constants of the decrease of flow in core, housing and armature.

If we disregard the effect of constant time of armature due to its low value, then

$$\tau'_{в} \approx \tau_{в1} + \tau'_{в2}.$$

Let us substitute into last/latter expression for $\tau'_{в1}$ and $\tau'_{в2}$ their value for the optimum relationship/ratios of reluctances from equations (11-14) and and (11-19c), assuming that $\delta_{01}$ = of $\delta_{02}$ = $\delta_0/2$:

$$\tau'_{в} \approx \frac{\mu_0 l_c r^2}{2\delta_{01} 5{,}78 \rho_1} + \frac{\mu_0 l_к a^2 b^2}{2\pi^2 \rho_1 \delta_{02}(a^2+b^2)} = \frac{4\pi \cdot 10^{-7} \cdot 7 \cdot 10^{-2} \cdot 0{,}45^2 \cdot 10^{-4}}{2 \cdot 0{,}01 \cdot 10^{-2} \cdot 5{,}78 \cdot 10{,}5 \cdot 10^{-8}} +$$

$$+ \frac{4\pi \cdot 10^{-7} \cdot 8{,}5 \cdot 10^{-2} \cdot 2{,}06^2 \cdot 0{,}4^2 \cdot 10^{-4}}{2\pi^2 \cdot 10{,}5 \cdot 10^{-8} \cdot 10^{-4} (2{,}06^2 + 0{,}4^2) 10^{-4}} = 0{,}0245 \text{ сек.}^{(1)}$$

Key: (1). s.

2. Relay of type RPN is loaded by two contact groups u. Adjustment of relay normal, the course of armature 1.1 mm the thickness of nonmagnetic antistick strip 0.2 mm. **Coil has two windings:**

$$w_1=8000,\ R_1=600\ \text{ом}^{(1)}\ \text{и}^{(2)}\ w_2=3000,\ R_2=140\ \text{ом}^{(1)}.$$

**Key: (1). ohm. (2). and.**

The first winding is included on battery with voltage 60 V.

Let us determine the releasing time of relay with the disconnection (disruption) of the circuit of the first winding, if the second winding is extended or shortcircuited.

With the aid of table 11-1 we find the load of the retention of **the relay:**

$$F=2\cdot 65=130\ \text{г}^{(1)}.$$

Key: (1). g.

If we consider the probable deviation of the thickness of anticorrosive coating and load of armature by the safety factor, equal to 1.5, then we will obtain maximally possible load of **the retention:**

$$F_m=1{,}5\cdot 130=195\ g.$$

The magnetizing ampere-turns of relay are equal to:

$$AW = \frac{60 \cdot 8000}{600} = 800 \text{ (1)}.$$

Key: (1). ampere-turns.

The releasing time of relay with the disconnection of the first winding and the extended second winding, according to curve, given in Fig. 11-5, will be respectively equally to: $t_0' = 18.5$ ms and $t_{01}' = 13.5$ ms.

With the shortened winding, which fills whole winding space of coil ($C_н = 4{,}5 \cdot 10^{-6}$ ohm), the releasing time of our relay, according to the curves of Fig. 11-5, will be equal to $t_{он} = 165$ to ms and $t_{он1} = 115$ ms. The releasing time of relay with disconnection to the first and shortened second winding we compute by formula (11-35); we have:

$$t_{от} = \frac{4{,}5 \cdot 10^{-6} \cdot 3000^2}{140} (165 - 18{,}5) + 18{,}5 = 61 \text{ (1)}$$

and

$$t_{от1} = 0{,}289 \cdot (115 - 13{,}5) + 13{,}5 = 42{,}5 \text{ (1)}.$$

Key: (1). ms.

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If with the shortened second winding the first winding is switched off by shorting, then the releasing time of relay in this case with respect increases according to formula (11-37b):

$$t_{\text{от}} = 4{,}5 \cdot 10^{-6} \left(\frac{3000^2}{140} + \frac{8000^2}{600}\right) \cdot (165 - 18{,}5) + 18{,}5 = 131 \text{ мсек}^{(1)}.$$

and

$$t_{\text{от1}} = 0{,}769 \cdot (115 - 13{,}5) + 13{,}5 = 91{,}6 \text{ мсек}^{(1)}.$$

Key: (1). ms.

3. Let us determine releasing time of time-lag relay of type RKN whose winding is shunted by resistor/resistance 100 ohm.

The full load of relay 300 g. Height/altitude of plug 0.1 mm. Turn number of winding 6000, resistor/resistance 500 ohm. Length of red copper plug 25.5 mm.

From table 11-2 we find that $C_{\text{кв}} = 4{,}59 \cdot 10^{-6}$ ohm. On the curves of Fig. 11-7 with F = 300 g and $\delta_0$ = 0.1 mm we find: $t_{\text{он}} = 290$ ms and $t_0'$ = 43 ms.

The releasing time of relay, according to formula

(11-37), will be equal to:

$$t_{\text{от}} = 3,2 \cdot 10^{-6}\left(\frac{10^6}{4,59} + \frac{6000^2}{500+100}\right) \cdot (290 - 43) + 43 = 263 \text{ мсек}^{(1)}.$$

Key: (1). ms.

4. Let us determine tentative value of releasing time of valve type relay with pole piece with disconnection and shorting of its winding.

Weight will stop the magnetic circuits of relay 80 g (weight of relay of approximately 200 g), the load of armature 100 g, the height/altitude of the plug of loosening 0.1 mm. The winding of relay fills the part of the winding space of coil, the value of equivalent resistance of one turn of winding $C = 0,5C_{\text{н}}$. The magnetizing ampere-turns are equal to 600 ampere-turns.

The releasing time of relay with the disconnection of winding, according to formula (11-40a), will be:

$$t'_{0} \approx \frac{30 \cdot 0,08}{\sqrt[4]{0,1^3 \cdot 0,1^3}} = \frac{2,4}{0,0463} = 52 \text{ мсек}^{(1)}.$$

Key: (1). ms.

Releasing time which has relay with the shorting of the winding, filling whole winding space of coil, according to formula (11-40b), is equal to:

$$t_{\text{он}} \approx \frac{1200\sqrt{0,08^3}}{0,0463} = 587 \text{ ms}.$$

Releasing time of relay with the shorting of the winding, which has $C = 0{,}5C_{n}$. according to formula (11-35)

$$t_{\text{от}} = \frac{1}{0{,}5}(587 - 52) + 52 = 319{,}5 \text{ мсек}^{(1)}.$$

Key: (1). ms.

5. Let us determine releasing time of relay of type RKN whose winding is shunted by capacitance/capacity in 30 μF.

The winding of relay has 80,000 turns of wire as a diameter 0.05 mm, winding impedance 32,000 ohm.

Value of the spill current 1.8 mA, of the current of release/tempering 0.54 mA. Voltage of battery 110 V.

The coefficients of reserve and return of relay are respectively equal to:

$$K_1 = \frac{110 \cdot 10^3}{32000 \cdot 1{,}8} = 1{,}9 \text{ и}^{(1)}\ k_{\text{в}} = \frac{0{,}54}{1{,}8} = 0{,}3.$$

Key: (1). and.

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Value of quantity

$$C_K R \frac{K_1}{k_B} = 30 \cdot 10^{-6} \cdot 32\,000 \cdot \frac{1,9}{0,3} = 6,08.$$

The value of optimum resistor/resistance $r_c$ must be within the limits

$$r_c = (0,27 \div 0,50) \frac{110}{0,54 \cdot 10^{-8}} - 32\,000 = 23\,000 \div 70\,000 \text{ ом}^{(1)}.$$

Key: (1). ohm.

From the curves of Fig. 11-31, we find the average value of the greatest releasing time of relay $t_{отп} = 2,6$ s.

According to curves of Fig. 11-32 this time can oscillate on the average within limits from 5.5 to +4.4o/o. The great probable deviation of the releasing time of relay will not exceed ±7.5o/o.

End Section.

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Chapter [redacted] twelve.

# EFFECT OF CLIMATIC AND MECHANICAL EFFECTS ON THE WORK OF RELAYS.

## 12-1. Temperature effect.

The fluctuations of ambient temperature change the linear dimensions of the core, housing, armature and other parts of relay, and also the value of the modulus of elasticity of the material of contact and return springs. As a result, in the points of connections (welding or junction) of separate parts and assemblies of relay appear mechanical stresses, are formed slants, is wedged the rotational axis of armature, change the coefficients of

friction in the radial bearings of armature and at the points of contact of the tangency of pushers, which transmit effort/forces from armature to contact springs, etc.

Therefore the working and ballast air gaps of magnetic relay circuit during the fluctuations of temperature change their value. the reactive effort/forces, created by contact and return springs, decrease with an increase in the temperature, since the temperature coefficient of the modulus of elasticity of spring materials is negative.

Thus, tar paper of function and release/tempering of electromagnetic relays during changes in the ambient temperature do not remain constants. During large cycle variations of temperature, are attenuate/weakened the screw joints, under the prolonged effect of high positive temperatures, ages the insulation of winding, changes the structures of the material of springs and decreases the limit of its elasticity, but this is led to the irreversible changes in the spill currents and release/tempering.

The heaviest testing for relay is a rapid (for time it is not more than 3 min) change in the temperature of

surrounding air from extreme negative to the greatest positive value, and vice versa, called the cyclic effect of temperature or thermal shock. Cycles are repeated 3-5 times with delay at extreme temperatures not less than two hours.

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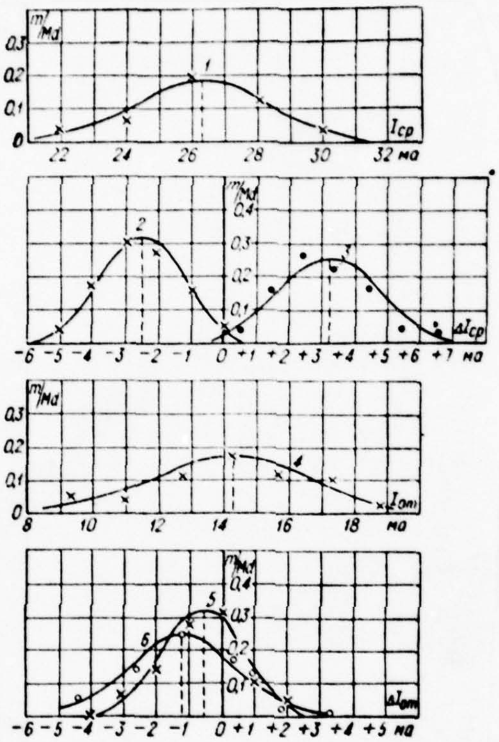


Fig. 12-1. Curves of the current distribution of function and release/tempering of the relay of the type RES6 and of their increments at different temperatures. 1 - spill currents with θ = +20°C: $\bar{I}_{cp}=26{,}3$ mA, $\sigma$ = 2.09 mA; 2 - increment in the spill currents with θ = +85° C: $\Delta\bar{I}_{cp}=-2{,}5$ mA, $\sigma$ = 1.24 mA; 3 - increment in the spill currents with θ = -60°C: $\Delta\bar{I}_{cp}=3{,}2$ mA, $\sigma$ = 1.54 mA; 4 - currents of release/tempering with θ = +20°C: $\bar{I}_{от}=14{,}26$ mA, $\sigma$ = 2.35 mA; 5 - increment in the currents of release/temparing at

$\theta$ = +85°: $\Delta\bar{I}_{\text{от}} = -0{,}62$ mA, $\sigma$ = 1.26 mA; 6. increment in the currents of release/tempering with $\theta$ = -60°C: $\Delta\bar{I}_{\text{от}} = -1{,}2$ mA, $\sigma$ = 1.53 mA.

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The greatest changes in the spill currents and release/tempering during the fluctuations of ambient temperature usually are observed in the highly sensitive and polar relay.

Figures 12-1 gives differential the curves of the current distribution of function and release/tempering of relay of the type RES6 with two stud switches under normal conditions (+20°C) and the curves of increments in the spill currents and release/tempering of these relays during short-term (2h) changes in the ambient temperature from +20°C to +85°C and +20°C to 60°C (winding impedance of relay 550 ohm, $M_0$ = 40). From these curves it follows that average current of the function of relay with an increase in the ambient temperature to +85°C decreases on 2.5 mA (9.5o/o), and during a temperature decrease to -60°C, it increases on 3.2 mA (12.2o/o). The

root-mean-square deviation of increments in the spill current at temperature of +85°C, is equal to 1.24 mA a at -60°C it equal to 1.54 mA. After the stay of relay at extreme temperatures, average current of function will increase on 0.6 mA (2.3o/o).

Average current of the release/tempering of relay with an increase in the temperature to +85°C decreases on 0.62 mA (4.4o/o) a during a temperature decrease to -60°C it decreases on 1.2 mA (8.4o/o). The root-mean-square deviation of the currents of the release/tempering respectively are equal to 1.26 and 1.53 mA.

After the stay of relay at extreme temperatures, average current of release/tempering decreases on 0.86 mA (6.06o/o).

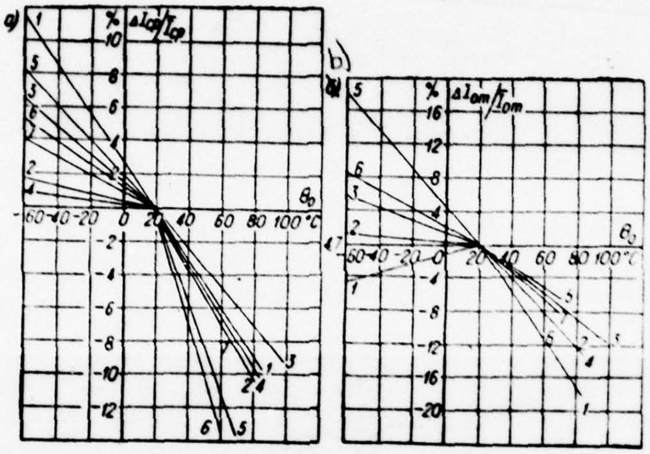


Fig. 12-2. Dependence curves of relative changes in average currents of function and release/tempering of the different types of relay from the temperature: a) spill currents; b) the currents of release/tempering. 1 - type RES6; 2 - type RES~~A~~9; 3 - type RES10; 4 - type RMU, 5 - type RS-52; 6 - type RS-13; 7 - type RKMP.

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Figures 12-2 gives the tentative curves of relative changes (in percentages) in average currents of actuation and release/tempering of some types of relay during the

short-term (2-hour) fluctuations of the temperature of surrounding air from -60 to +(60-100) °C, constructed according to the data of studies T.K. ~~SINCE~~ Shtremberg.

From these curves it follows that average currents of the function of all types of relay and currents of release/tempering the majority of the types of relay (with the exception of relay of the type (RES6) decrease with an increase in the ambient temperature from +20°C and increase with its decrease. A change in average currents of function of the various types of relay oscillates within limits from 1 to 13o/o, while values of the currents of release/tempering - from 0 to 19o/o. The root-mean-square deviation of increments in the spill currents during temperature changes oscillates within limits approximately from 3 to 12o/o, while those in the currents of release/tempering - from 8 to 25o/o.

Under the prolonged influence of elevated temperature, ages the insulation of wire, appear shortcircuited turns and winding goes out of order.

Figures 12-3 shows the integral distribution curve of breakdowns of relay of the type RES6 with winding impedance

2500 ohm at current 24 mA and ambient temperature +85°C; m - a quantity of relays, which broke down and $M_0$ - the total quantity of tested relays ($M_0$ = 20). From this curve it follows that at the temperature of +85°C relay they begin to go out of order for 350 h, and for 700 h appear closed loops of half (50o/o) of tested relays.

Pressure in the contacts of relay under the prolonged influence of temperature decreases.

Figures 12-4 gives differential the distribution curves of pressure in the contacts of relay of the type RES6 before and after 1000 h of the work of these relays during temperature +85°C ($M_0$ = 80). These curves show that for 1000 h of work with +85°C in 45o/o of breaking contact the pressure falls below 12 $\Gamma$, in 10o/o - below 8 $\Gamma$.

With an increase in the temperature decrease the insulation resistance and the breakdown voltage of relay.

Figures 12-5 gives curved changes in the insulation resistance of the relay of types RMU RES6 and RKN from temperature.

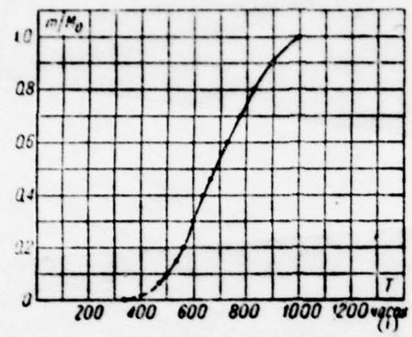


Fig. 12-3. The distribution curve of breakdowns of relay of the type RES6 according to time at ambient temperature of +85°C. $M_0$ is the total quantity of tested relays ($M_0$ = 20); m - a quantity of specimen/samples, which left the system; r = 2500 ohm; I = 24 mA; $\theta_M \sim 192°$ C.

Key: (1). hours.

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The curves of the insulation resistance of contact system relative to housing are depicted by solid lines, and between winding and housing broken lines. From these curves it follows that with an increase in the temperature from

+20 to +100°C insulation resistance decreases approximately ten time.

As a result of an increase in the erosion due to an increase in the concentration of organic vapors, isolated by insulation, the service life of the contacts of airtight relays with an increase in the ambient temperature from +20 to +100°C is usually decreased on the average two or three times. Defect level with the very light loads of contacts with an increase in the temperature increases.

The great value of the contact resistance of airtight relays with an increase in the ambient temperature from +20 to +100, +125°C takje considerably increases, apparently, due to an increase in the concentration of organic vapors (see § 18-8).

During the fluctuations of the low temperature of surrounding air from 0 to -(20-60) °C are observed the failures of the open and dustproof relays as a result of the icing of contacts. A quantity failures of contacts in this case depending on air humidity usually varies within limits from 0.5 to 2o/o.

With lowering in the atmospheric pressure, increases the temperature of the overheating of winding, decreases the service life of contacts and considerably is reduced the breakdown voltage of insulation of winding and contacts of relay.

At the lowered/reduced atmospheric air pressure and with voltage of approximately 300 v the ampl. between contacts also on the projecting chisel edges of the contact springs and other current-carrying parts of the relay appears the glowing (calm) discharge in the form of weak violet glow.

Dielectric strength of air reaches the minimum value at atmospheric pressure in several millimeters of mercury.

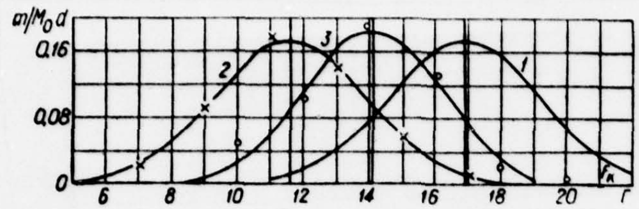


Fig. 12-4. Distribution curves of pressure in contacts of relay of type RES6 before and after 1000 h of work at temperature of +85°C. 1 - before tests, $\theta_к = 20°$ C, $\bar{F}_к = 16{,}9$ Г, $\sigma = 2{,}28$ Г, $M_к = 80$; 2 - breaking contact $\bar{F}_к = 11{,}6$ Г, $\sigma = 2{,}22$ Г; 3 - circuit closing contacts $\bar{F}_к = 14{,}1$ Г, $\sigma = 2{,}2$ Г.

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The glowing discharge is accompanied by hot spot at isolated points, by radio interferences and the formation of ozone and nitrous connections, which detrimentally operate on metals and insulation of relay.

During interrupting of the circuit of the winding of relay even with low voltages (12-26v) the amplitude of overvoltage frequently exceeds 1200-1500 v. Therefore under

conditions of the lowered/reduced atmospheric pressure, it is necessary to apply the airtight relays within which is retained normal atmospheric pressure.

The conclusion/derivations of airtight relays are usually insulated from housing by the glass insulating beads whose diameter is equal about 3 mm, and arcing distance (leakage path) is about 1 mm.

The breakdown voltage of these insulating beads at a normal atmospheric pressure is more than 2000 V eff. (at frequency 50 GHz), at altitude 15 km (pressure ~70 mm Hg) are about 700 V eff., at height/altitude 24 km (~17 mm mm Hg) - about 350 v and at the height/altitude thof 42.5 km (~4 mm Hg) - about 200-225 V eff. [L. 18-33].

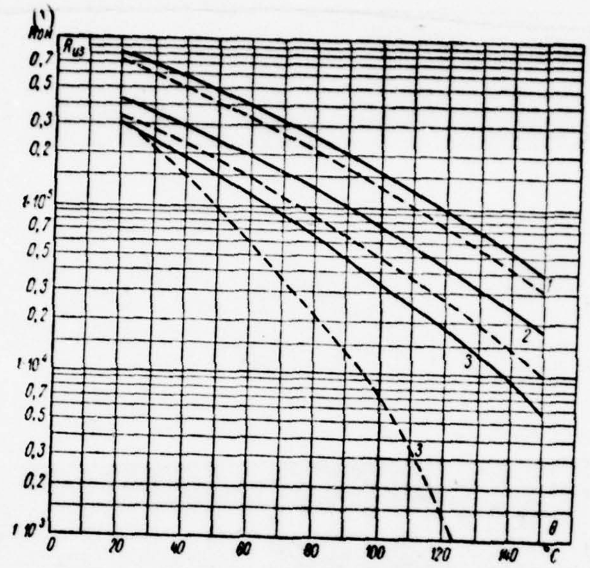


Fig. 12-5. Curved changes in the insulation resistance of relay from temperature. 1 - relay of the type MU; 2 - relay of the type RES6; 3 - relay of the type KN.

Key: (1). MΩ.

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Therefore for the protection of insulating beads and leading-out pins of airtight relays at high altitudes from the formation/education of the glowing discharge, it is necessary the base of relay with insulating beads and pins,

to which are soldered isolated/insulated lead wires, to pour outside foam sealant.

The amplitude of overvoltage can be considerably decreased by means of connection/inclusion in parallel to the winding of the relay of miniature varistor (§ 19-2).

At the lowered/reduced atmospheric pressure the testing voltage of insulation is must be higher than operating voltage and potential difference among any contacts and the winding not less than to 50o/o. At atmospheric pressure 41 mm Hg, the testing voltage of insulation of relay must not exceed 500 V eff., at the pressure 15 mm Hg - 300 V eff. at a pressure of approximately 5 mm Hg - 200 V eff.

The effect of atmospheric pressure on the temperature of the overheating of the winding of relay and the period of service of contacts is examined into § 9-6 and 18-6.

12-2. Effect of the increased humidity.

At the prolonged action of the increased humidity of

ambient air (95-98o/o) and temperature +20 or +40°C, considerably is reduced the electrical insulation resistance of the winding of relay and contacts, increases the thickness of getinax separators, at the metallic parts of relay, appear the films of oxides and the traces of corrosion, change the coefficients of bearing friction and at the points of transmission with the pushers of effort/forces from armature to movable contact springs, and the limiters of the course of the armature of the relay of the open performance afterward breakings in sometimes "adhere" to housing. Therefore after the stay of the open (nonhermetic) relays under conditions of the increased humidity, change the spill currents and release/tempering. Spill currents usually increase by 10-15o/o, a great increase occurring after the prolonged idleness of relay.

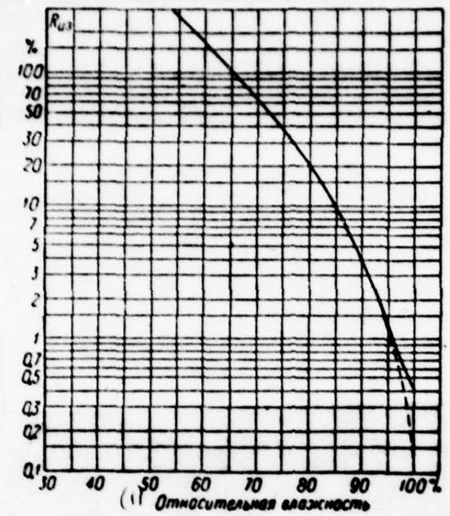


Fig. 12-6. Curved changes in the insulation resistance (in c/o) from the value of relative humidity.

Key: (1). relative humidity.

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The adhesion of the travel limiters of the armature of the partially worn relays sometimes is so powerful that even the operating current proves to be insufficient for function relay. The cause of this adhesion thus far is not establish/installed. It is assumed that the wear products of

limiters (metallic dust) at the points of their contact with housing with accumulation under conditions of humidity are oxidized under the action of local galvanic vapor and are cemented, fastenning the limiters of armature with housing.

In airtight constructions the spill currents and release/tempering of relay do not depend on the humidity of the external surrounding air. The insulation resistance of relay decreases with an increase in the relative humidity of surrounding air. The tentative curves percentage change in the insulation resistance of relay (insulation of class A from the value of relative humidity are given in Fig. 12-6. From these curves it follows that the insulation resistance sharply falls with relative humidity more than 90o/o.

A) the open (nonhermetic) relays.

In Fig. 12-7 are constructed the differential curved of resistancc distributions of insulation between winding and housing of relay of the type RES6 after 6 h of stay at

relative humidity 98-100o/o and temperatures +20 and +40°C.

Along the axis of ordinates, is deposit/postponed the experimental probability density of insulation resistance $m/M_0d$ (where m - a quantity of relays, resistive of insulation in this interval, $M_0$ - the total quantity of tested relays and d - the length of interval), while along the axis of abscissas, is deposit/postponed the logarithm of the insulation resistance of relay.

The integral distribution curves of insulation resistance between housing and winding of relays of the type RES6, constructed on a logarithmic-probabilistic grid, are given in Fig. 12-8.

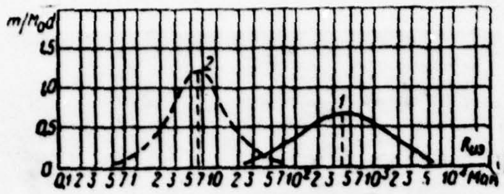


Fig. 12-7. Differential curved drag distributions of insulation between winding and housing of relay of type RES6 after 6 h of stay during relative humidity 98-100o/o. 1 - temperature +20°C; 2 - temperature +40°C.

Key: (1). MΩ

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Along the axis of ordinates, is deposit/postponed the probability of obtaining the specimen/samples of relay with the datum of insulation resistance $M/M_0$ where M - a total quantity of specimen/samples), which have $R_{из}$ not of the more corresponding value on the axis of abscissas (according to the data of the studies of L. V. Polikarpovoy).

From these curves it follows that the drag distribution of insulation of relay is subordinated to lognormal law. At

relative humidity 98-100o/o and temperature +40°C root-mean-square deviation of the logarithm of insulation resistance 1.8 times less than at the same humidity and temperature +20°C.

Dependence curves of most probable (average) values of the insulation resistance of winding and contacts of the different types of relay from retention time under conditions of relative humidity 95-98o/o (at temperatures of +20°C and +40°C) are given in Fig. 12-9.

Recovery characteristic the insulation resistance of relay of the type RS-52 after their withdrawal from sweat box are shown in Fig. 12-10.

From these curves it follows that the insulation resistance of the windings of the relay of types RS-52 and PES 6 under conditions of humidity 98-100o/o at temperature of +20°C for 48 h falls to 30-10 MΩ, but at temperature of +40°C q- to 2.0-0.4 MΩ.

After withdrawal from sweat box, the insulation resistance of the winding of relay of the type -52 for 1 h increases to 5-35 MΩ and completely it is restored approximately for 50 h.

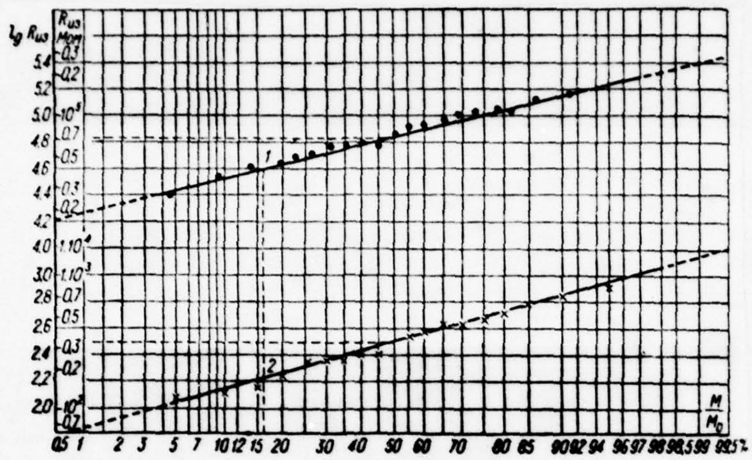


Fig. 12-8. The integral distribution curves of the insulation resistance of rerelay of the type RES6. 1 - before tests, $\theta_0$ = 20°C; 2 - after stay with relative humidity 90o/o for 48 h, $\theta_0$ = 40°C.

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The insulation resistance of contacts is restored considerably faster, approximately for 3 h.

Many insulation, as for instance, paper, fiber, the incompletely polymerized plastics, contain insignificantly a

quantity (traces) of salts or acids; therefore with the increased humidity between the current-carrying parts of relay and housing under the action of stray current, can occur the phenomenon of electrolysis. The greatest danger represents the electrolysis of windings from fine/thin copper wires, which are located under positive potential with respect to housing (core) or another winding with voltage more than 50 v, since the copper ions are positive. Under the action of stray current, the wire gradually is oxidized (it is corroded), and through certain time appear breaks in windings. Therefore for insulation of the winding of relay from core or adjacent winding and for external covering one should not apply paper and varnished insulating cloth; the best results gives film from polyfluorcethylene resin or cellulose acetates.

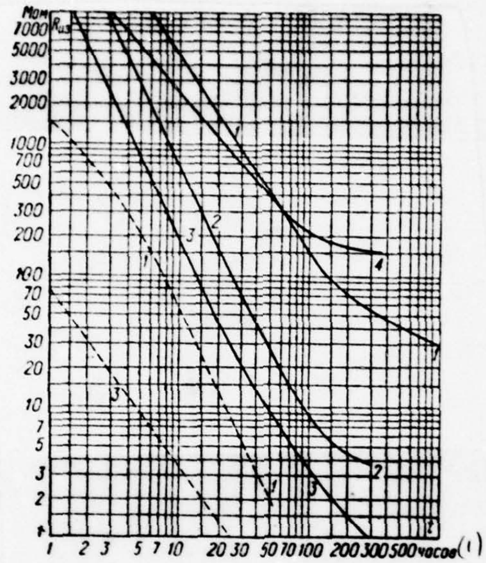


Fig. 12-9. Curved of the dependences of the insulation resistance of relay on retention time under conditions of relative humidity 95-98o/o; between winding and the housing: 1 - type RES10; 2 - type TSC-52; 3 - type RES6; between contacts and the housing: 4 - type RSC-52; ——— temperature +20°C; - - - temperature +40°C.

Key: (1). Hours.

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Enamel insulation of wire must not be contaminated. The relays with windings from fine/thin wires, intended for operation with the increased humidity and voltage are more than 50 v, they must be hermetically isolate/insulated or saturated with the varnishes, which do not contain the traces of acids.

Accelerated tests of the windings of relay for the action of electrolysis are conducted at increased humidity (95-98o/o) and temperature +30, +40°C. To plus of power supply through limiting resistor/resistance, is connected one of the end/leads of the winding of relay, which is located in sweat box; core or the second winding of this relay are connected with minus of power supply.

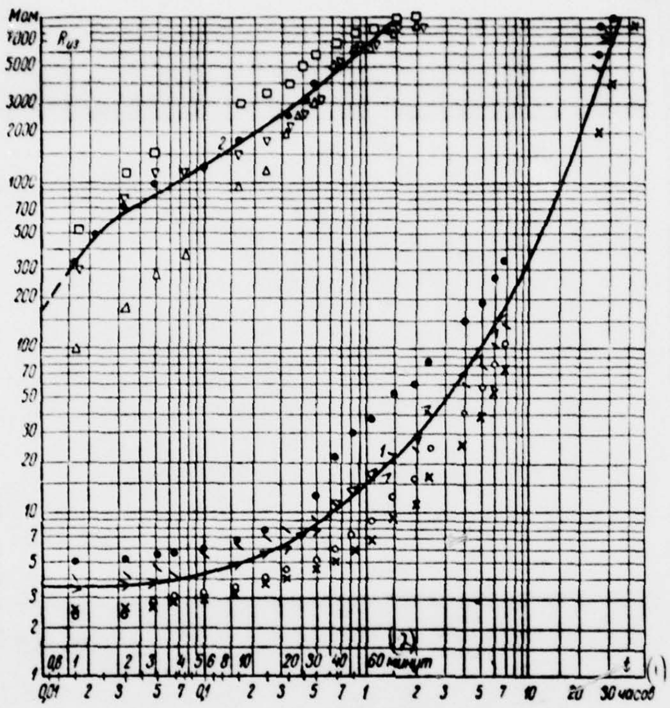


Fig. 12-10. Recovery characteristic the insulation resistance of relay of the type RSC-52. 1 - between winding and housing; 2 - between contacts and housing.

Key: (1). hours. (2). minute.

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Relays are maintain/withstood under conditions of the increased humidity and temperatures of 35-40 days; during this time periodically are checked resistance of winding and the resistor/resistance of its insulation.

For the exception/elimination of the harmful effect of electrolysis on the windings of the open (nonhermetic) relays, it is necessary to ground the positive pole (plus) of power supply or to insulate the housing (core) of relay from the earth/ground.

B) airtight relays.

Contemporary airtight relays have the vacuum-tight sealing/pressurization, coil leads and contacts they are realized with the aid of the pins from Kovar alloy, sealed in in glass insulating beads. The internal volume of relay is filled with dry air or inert gas.

As a result of the hygroscopicity (wettability) of the surface of glass and small path length of escape, the insulation resistance of relay under conditions of high

relative humidity (95±3o/o) for 48 h can sometimes be lowered approximately to 10 MΩ. Therefore insulating beads must be cover/coated outside with silicon varnish and shielded their surface from scratches, overheating and contamination during soldering.

Is restored the insulation resistance of relay under normal conditions very rapidly, for 2-10 min.

If insulation of coil form and other parts of airtight relays is made from the usual plastic, which isolates during heating a large quantity of moisture, then through several minutes after the connection/inclusion of winding this moisture condenses on the internal surface of glass insulating beads, and resistance of insulation of relay sharply falls. After the warm-up of the base of relay approximately after 20-30 min the moisture on insulating beads evaporates and insulation resistance increases.

In the case of the contamination of the internal surface of insulating beads by the residue/remainders of acid flux or electrolyte and condensations of moisture under the action of stray current begins the electrolysis of the metal of the base and conclusion/derivations, which can lead

in the course of time to large and stable decrease in the insulation resistance (to 1.0-0.1 MΩ).

At low minus temperatures -(20-60)°C moisture is deposited on the internal surface of relay and on contacts in the form of the hoarfrost, calling sometimes the failures of contacts due to their "icing".

The probability of the appearance of failures increases, if we after cooling of relay include/connect winding, since in this case entire/all moisture will be condensed on the considerably smaller and most cooled part of the internal surface of jacket, and also on the contacts, which have minus temperature.

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At large quantities of moisture and positive temperatures between dead contacts, can be formed the current-conducting water bridges, while with a potential difference among winding and housing more than 50 v can be begun the electrolysis, which leads to the decomposition of fine/thin wires ( § 18-9). Insufficiently shielded metallic surfaces of relay undergo in the course of time the action

of corrosion.

Therefore for the production of airtight relays, it is necessary to apply special insulation and the plastics, virtually which do not isolate during heating of aggressive gases and water vapors.

Before the sealing/pressurization of relay, they must be well degassed in vacuum thermostat at pressure $10^{-4}$ mm Hg and temperature +170°C and are filled by dry air or the inert gas, which has the dew point not above -(65-70) °C.

However, during changes in temperature and pressures of surrounding air, water vapors can penetrate the housing of airtight relay, through smallest defects in the junctions of jacket with the base and of glass insulating beads with conclusion/derivations and with base since molecules of water vapors have very small size/dimensions (leakage rate of water vapors only to 10o/o less than of hydrogen and 1.8 times more than of air).

If humid air fills in the course of time only 10o/o of internal volume of relay, then the dew point of the filling gas will rise from -(65-70)°C approximately to -55°C

and with surrounding temperature -(55-60)°C contacts can give failures.

Therefore to the airtightness of relay, are presented very high requirements. Soldering jacket to avoid the oxidation of solder must be conducted in the atmosphere of hydrogen.

So that in 10 years of operation inside relay will penetrate less than 10o/o space of humid air, it is necessary that the leakage rate of gas from the housing of miniature relay does not exceed $2 \cdot 10^{-8}$ $cm^3/s$.

The measurement of this small escape under conditions of series production is very difficult problem, since for this purpose it is necessary to use mass spectrometer or very sensitive leak detector.

In connection with the fact that the gas escape from the housing of relay is detected usually by the escape of helium atoms, into the composition of the gas, which fills relay, is added about ~~10/o~~ 10% of helium.

C) the dustproof relays.

Dust-protected relays do not have the vacuum-tight airtightness. With an increase in the relative humidity of surrounding air, the moisture gradually penetrates inside relay and is delayed there for a prolonged time due to the absence of ventilation.

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Therefore the dustproof relays usually more suffer from the action of the increased humidity, than the open relays. Metallic parts undergo the action of corrosion, insulation resistance is reduced, more frequently are observed the electrolysis of windings, the formation/education of the water bridges between contacts and the "icing" of contacts at minus temperatures.

12-3.

During the use of relay in movable objects or in the

stationary equipment, which undergoes the action of the vibrations, caused by operating by a series engines or machines, on relay affect the external mechanical vibration overloadings of different amplitude and frequency.

These overloadings cause the periodic oscillations of all motionless and moving elements, which is led to a change in the spill currents and release/tempering of relay.

spill currents under conditions of the vibration of relay usually a little decrease (to 4-25o/o) as a result of periodic decrease of working air gap in magnetic circuit and a decrease in the coefficients of bearing friction and pushers (backstops) of armature, while the currents of release/tempering increase (to 8-75o/o) due to a periodic increase in the load of armature.

Furthermore, under the action of overloadings periodically change effort/forces (pressure) in the locked contacts.

If frequency of the external forcing coincides with the frequency of the free (its own) of housing, magnetic circuit, movable system or contact springs, then occurs

resonance. The amplitude of the oscillations of these parts (parts) sharply grow/rises, leading to the periodic interruptings of locked or the closing/shorting of dead contacts, and in certain cases and to the damage (breaking) of the separate parts of relay or the break of lead wires from winding.

Therefore relay must be constructed so that the resonance frequencies of all parts and parts (housing, magnetic circuit, movable system, contact groups, return springs and lead wires) will be as far as possible higher than range of the assigned frequencies of the forcing, but a decrease in the effort/forces in the locked contacts under the effect of vibration does not fall below specific minimum value, ensuring the reliable work of contacts.

Vibration stability of relay is usually determined by the frequency band and amplitudes (accelerations) within limits of which they are absent spontaneous interruptings or the closing/shortings ("auto/self-function") of contacts.

The movable and contact systems of relay in dynamic sense are the complex system, which is of armature with reduced mass and the elasticity of return spring, and

flexible contact system with one, two four or six contact groups.

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Contact group with the closing or breaking contact consists of two contact springs with contacts on end/leads, and group with stud switches - of three contact springs.

In contact group with stud switch in the absence of coil current of relay, the free end/lead (contact) of average (movable) spring rests on the contact of lower (motionless) with the specific effort/force (pressure in contact).

Upper and lower (motionless) contact springs are the bracket whose free end/lead sometimes rests on supporting spring or rigid backstop.

Upon the connection/inclusion of the winding of relay, average spring with the aid of the pusher of armature is remove/taken from lower and is pressed against upper spring, in this case the contacts are changed over.

Thus, the natural frequencies of armature, movable and motionless contact springs are different. Under the influence on the relay of the external vibration overloadings of different frequency, the normally closed contacts of relay begin to be broken (to auto/self-wear/operate) at the resonance frequencies of an entire system, which consists of movable and contact systems.

The determination of the resonance frequencies of the complex system is connected with great difficulties. the analysis of the fluctuations of armature and contact groups is given in the book R. Pik and G. Ueygar [1. 4-33].

Let us examine the fluctuations of the separate flat/plane cantilever spring, attached by one end/lead. n1 the frequency of the free (its own) elastic single-degree-of-freedom system is determined by following expression [1. 2-7]:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{g}{y}}, \qquad (12\text{-}1)$$

where g - acceleration of gravity and y - static deformation (sagging/deflection) of spring.

The value of the static deflection of flat/plane

cantilever spring under the action of the concentrated weight of contact $Q_к$ and of the dead weight of spring Q will be equal to:

$$y = \frac{\left(Q_к + \frac{Q}{4}\right) l^3}{3EJ} = \frac{Ql^3 (4n+1)}{Ebh^3} = \frac{\gamma l^4 (4n+1)}{Eh^2}, \qquad (12\text{-}2)$$

where E - modulus of elasticity of the material of spring in kgf/cm²; J is the second moment of area of spring; $\gamma$ is material density of spring in g/cm³; b h and $l$ - width, thickness and the length of spring in cm; n is ratio of the weight of contact to the weight of spring.

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Substituting in equation (12-1) instead of u its value from last/latter expression, we obtain:

$$f_0 = \frac{h}{2\pi l^2} \sqrt{\frac{981 \cdot 10^3 E}{\gamma (4n+1)}} = \frac{158h}{l^2} \sqrt{\frac{E}{\gamma (4n+1)}}. \qquad (12\text{-}3)$$

For flat/plane cantilever springs from white copper without contacts (n = 0) natural frequency:

$$f_0 = \frac{158h}{l^2} \sqrt{\frac{E}{\gamma}} = 58 \cdot 10^3 \frac{h}{l^2}. \qquad (12\text{-}3a)$$

Figures 12-11 gives curves, constructed by author with the aid of formula (12-~~1~~3a).

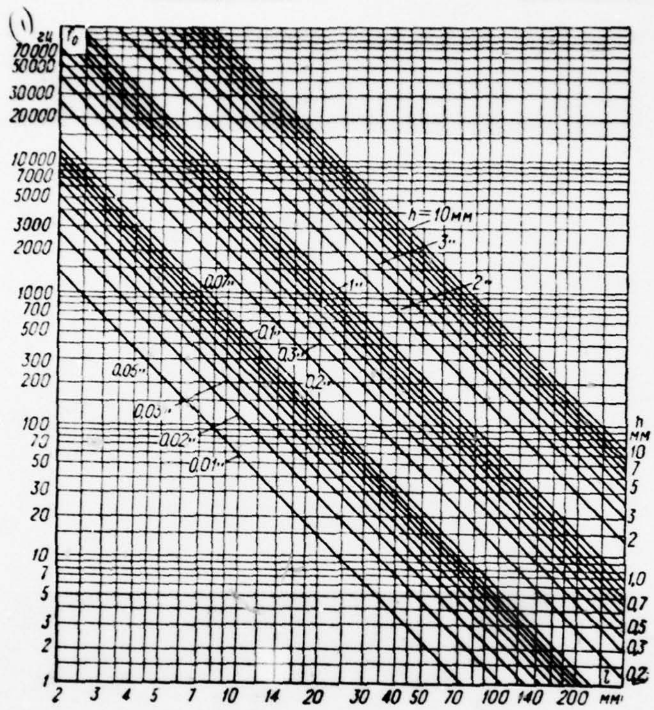


Fig. 12-11. Curved of the dependences of the natural frequency of flat/plane cantilever springs from white copper on the length of these springs with their different thickness.

Key: (1). Hz.

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AD-A066 135 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 9/1
CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)
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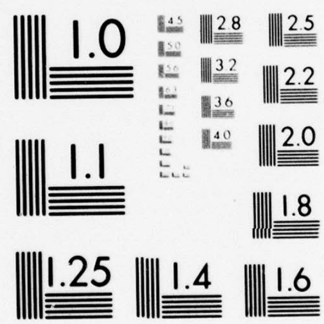


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

For flat springs, prepared from the phosphor bronze, the value of natural frequency, found from the curves of Fig. 12-11, must be multiplied by 0.98; for springs from silicomanganic bronze - by 1.03; for springs from beryllium bronze - by 1.08 and for springs made of strip spring steel - by 1.37. The static deflection of the cantilever spring of round cross-section (wire spring) is equal to:

$$y = \frac{Ql^3(4n+1)\cdot 64}{12E\pi d^4} = \frac{4\gamma l^4(4n+1)}{3Ed^2}, \qquad (12\text{-}2a)$$

where d and $l$ - a diameter of section and the length of spring in cm.

Natural vibration frequency of the cantilever spring of the round cross-section

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{3Egd^2}{4\gamma l^4(4n+1)}} = \frac{137d}{l^2}\sqrt{\frac{E}{\gamma(4n+1)}}. \qquad (12\text{-}4)$$

For the cantilever springs of round cross-section from white copper without contacts) natural frequency

$$f_0 = \frac{137d}{l^2}\sqrt{\frac{E}{\gamma}} = 50\cdot 10^3\frac{d}{l^2}. \qquad (12\text{-}4a)$$

The amplitude of forced oscillations

$$s = \frac{F_m}{m\sqrt{(\omega_0^2-\omega^2)^2+4\omega^2\eta^2}}, \qquad (12\text{-}5)$$

where $F_m$ is amplitude of sinusoidal perturbing force, m - reduced mass, ω and $\omega_0$ - the angular perturbation and resonance frequencies and η - the damping coefficient.

Curves, given in Fig. 12-11, it is possible to also use for determining the natural frequency of the cantilever springs of round cross-section (without contacts), if instead of the thickness of spring h to plot its diameter d and obtained from curve/graph results to multiply by ratio 50/58 = 0.86.

If the free end/lead (contact) of cantilever spring rests on rigid support (fixed contact), then the frequency of the fundamental harmonic of the free fluctuations of this spring will be 4.4 times more than in the not supported spring [1. 4-33]:

$$f_1 = 4{,}4 f_0. \qquad (12\text{-}6)$$

The frequency of quadratic component will be equal to $f_2$ = 14.2 $f_0$, and by the third $f_3$ = 29.5•$f_0$.

Therefore for an increase in the vibration resistance of the contact systems of relay, it is necessary that the

free end/leads of the movable cantilever springs rest on fixed contacts or backstops, and motionless" springs also have supports.

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The natural frequency of cantilever springs increases proportional to the thickness of spring and inversely proportionalto square length; however, in this case they decrease the value of the permissible spring sag, which determines the great distance between contacts.

The value of the greatest permissible sagging/deflection of flat spring, according to formula (3-5), is equal to:

$$y_m = \frac{2}{3} \cdot \frac{l^2 k_n}{hE}.$$

From formula (12-3a) we find:

$$\frac{l^2}{h} = \frac{158}{f_0} \sqrt{\frac{E}{\gamma}}.$$

Substituting in expression for the greatest permissible sagging/deflection of flat spring $y_m$ instead of ratio $l^2/h$ its value from last/latter expression, we obtain the dependence of value $y_m$ from the natural frequency of the spring:

$$y_m = \frac{2}{3} \cdot \frac{k_n 158}{Eh} \sqrt{\frac{E}{\gamma}} = 105,3 \frac{k_n}{f_0} \sqrt{\frac{1}{E\gamma}}. \qquad (12\text{-}7)$$

For flat springs from extra-hard white copper

$$y_m = \frac{74.5}{f_0}. \qquad (12\text{-}7a)$$

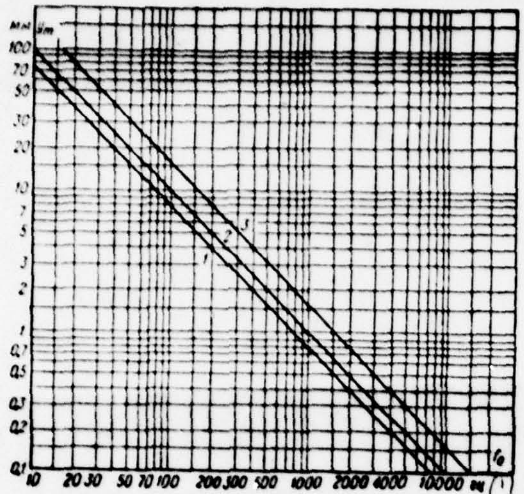


Fig. 12-12. Dependence curves of the value of the greatest sagging/deflection due to the natural frequency of flat springs from different materials. 1 - bronze phosphorous and silico-manganic, white copper; 2 - beryllium bronze; 3 - steel is spring.

Key: (1). Hz.

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To Fig. 12-12, are given dependence curves of the value of the greatest sagging/deflection $y_m$ due to natural frequency for flat springs, prepared from different materials.

The resonance frequencies of relay depend on the reduced masses of armature, recurrent and contact springs, and also on thickness, length and the modulus of elasticity of these springs. The values of these quantities of the different specimen/samples of just one type relay vary within some limits, determined by production tolerances. Therefore the resonance frequencies of just one type relay oscillate within sufficiently large limits.

After the attraction of armature, contact system is changed over, appear the supplementary fulcrums of armature and springs, and the resonance frequencies of relay change.

If the armature of relay is not balanced or has the ample clearances in axes, then the resonance frequency of relay depends also on the direction effect acceleration force.

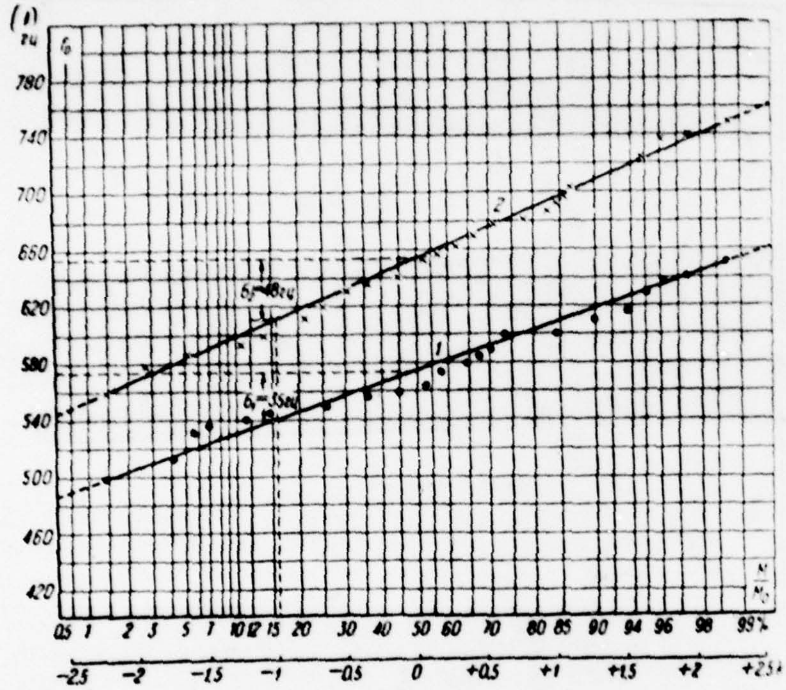


Fig. 12-13. The distribution curves of the resonance frequencies of the relay of the type RES6 ($N_0$ = 75). 1- breaking contact; 2 - circuit closing contacts.

Key: (1). Hz.

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To Fig. 12-13, are given the integral distribution curves of the resonance frequencies of the breaking and

circuit closing contacts of relay of the type RES6 with two stud switches in the absence of coil current and during the safety factor on static current (according to the data of research of T. K. Shtremberg).

Tests were carried out in the direction of acceleration force of the perpendicular to the plane contact springs of relay. Tested 75 contact groups to 38 relay ($N_0$ = 75).

From these curves follows that the resonance frequencies of the breaking contact of relay of the type RES6 oscillate within limits from 480 to 660 Hz [mathematical expectation $\bar{f}_p = 576$ Hz, root-mean-square deviation $\sigma$ = 34.8 Hz (6.05o/o)], and the resonance frequencies of circuit closing contacts - from 540 to 760 Hz [$\bar{f}_p = 654$ Hz and $\sigma$ = 48 Hz (7.35o/o)].

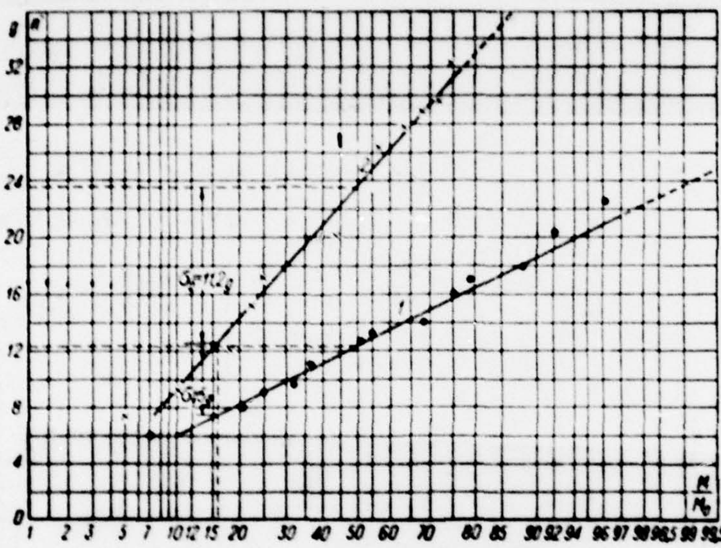

Fig. 12-14. The distribution curves of the acceleration limits during which auto/self-wear/operate (they are broken) the breaking contact of relay of the type RES6 during vibration on resonance frequencies. 1 - acceleration force is directed of perpendicular to the plane contact springs; 2 - acceleration force is directed along contact springs.

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To Fig. 12-14, are given the integral distribution curves of the acceleration limits during which auto/self-wear/operate (they are broken) the breaking contact

of relays of the type RES6 during vibration on resonance frequencies and the absence of coil current, constructed on probabilistic grid.

Testing was carried out under the influence of acceleration force in two mutually perpendicular planes.

From these curves it follows that in the direction of acceleration force of the perpendicular to the plane contact springs of relay are self-actuating at resonance frequencies during accelerations from 6 to 22.4 g. During acceleration 12.4 g, auto/self-wear/operated 50o/o of tested relays. Mathematical expectation is equal to 12.4 g and root-mean-square deviation σ = 5.0 g(40.3o/o).

In the direction of acceleration force along contact, springs of relay auto/self-wear/operate during accelerations from 7.5 to 32 g (larger acceleration it does not give vibration table).

The half of the tested relays auto/self-wear/operated at resonance frequencies during acceleration 23.8 g. Mathematical expectation is equal to 23.8 g and root-mean-square deviation σ = 11.2 g(47.1o/o).

For a decrease in the spread of parameters and increase in lower boundary of the acceleration during which occurs the auto/self-function of the contacts of relay, it is necessary to decrease the tolerances for the thickness of springs, to raise the accuracy of production and assembly of parts, and it is also more thorough to regulate relay.

Sometimes can be used the method of the selection of the most vibration-proof relays.

The value of acceleration during vibration can be determined with the aid of the formula:

$$n = 4{,}03 \cdot 10^{-3} f^2 s,$$

where n - acceleration in unity g (acceleration of gravity);

s - amplitude of oscillations in mm;

f - frequency in Hz.

12-4. Effect of uniform accelerations.

During use in movable equipment for relay, they undergo the influence of external mechanical g-forces - constant (linear) accelerations. These accelerations, operating on the movable and contact systems of relay, change its mechanical characteristic and, consequently, also the spill currents and release/tempering. With an increase in the accelerations, they can achieve such value under action of which the contacts of relay it is extended or they will be closed in the absence of coil current ("auto/self-wear/operate").

For decreasing the action of mechanical overloadings, it is necessary to counterbalance (to balance) the movable system of relay. However, of valve type, relay this is difficult, since it is necessary to apply the supplementary counterweights which increase the moment of the inertia of movable system, which leads to decrease in the vibration- and impact resistance and vibration- and the shockproof quality of relay.

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The stability of relay to the effect of uniform accelerations is determined by two values: changes in the spill currents and release/tempering under the effect of the uniform acceleration of the assigned magnitude and by the limiting value of acceleration with which they auto/self-wear/operate or do not release the contacts of relay.

Usually the stability of relay to the effect of uniform accelerations is determined from interrupting ("auto/self-function") of the breaking contact, since for closing/shorting or interrupting of circuit closing contacts usually is required larger acceleration.

Therefore as the acceleration of "auto/self-function" is accepted the small external acceleration during which are broken the breaking contact.

For determining the limiting value of the uniform acceleration, calling the "auto/self-function" of relay, it is necessary to examine the revolving and reactionary torque, which appear under the effect of uniform

acceleration on all parts of the movable system of relay in the most unfavorable direction.

Under the effect of uniform acceleration in the direction of the motion of movable contact springs (it is perpendicular to the plane of these springs) to interrupting the breaking contact contribute turning moments, created by the action of uniform acceleration on the masses of armature and contacts, and to the distributed masses - contact and return springs.

Turning moment, created by the action of uniform acceleration on the masses of armature and contact, it is possible to express by the following formula:

$$M_{як} = M_я + M_к = m_я n_1 g l_я + m_к n_1 g l_к = n_1 (Q_я l_я + Q_к l_к). \quad (12\text{-}8)$$

where $m_я$ and $m_к$ — the masses of armature and contact, $Q_я$ and $Q_к$ — the weight of armature and contact, g - the acceleration of gravity $n_1$ - the value of external uniform acceleration in the portions of the acceleration of gravity $l_я$ — the distance between centers of the rotation of armature and its center of gravity in the direction, perpendicular to the direction of the action of uniform acceleration and $l_к$ — the length of spring from the place of its seal to

the center of contact.

Turning moment, created by the action of uniform acceleration on the distributed masses of contact and return springs, it is possible to record:

$$M_{\text{квп}} = M_{\text{кп}} + M_{\text{вп}} = \frac{3}{8} n_1 g (q_{\text{кп}} l_{\text{кп}}^2 + q_{\text{вп}} l_{\text{вп}}^2) = \frac{3}{8} n_1 (Q_{\text{кп}} l_{\text{кп}} + Q_{\text{вп}} l_{\text{вп}}), \quad (12\text{-}9)$$

where $q_{\text{кп}}$ and $q_{\text{вп}}$ — the masses of the unit of the length of contact and return springs, $Q_{\text{кп}}$ and $Q_{\text{вп}}$ — the weight of the test sections of the contact and return springs and $l_{\text{кп}}$ and $l_{\text{вп}}$ — the length of the test sections of the contact and return springs.

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If relay has several contact groups and return springs, then common/general/total turning moment, created by the action of uniform acceleration on the movable and contact system of relay, will be:

$$M_{\text{вр}} = M_{\text{я}} + kM_{\text{к}} + kM_{\text{кп}} + k_1 M_{\text{вп}}. \quad (12\text{-}10)$$

where k is a number of contact groups of relay and $k_1$ - a number of return springs of relay.

This torque/moment opposes the torque/moment, created by the effort/forces of the contact and return springs:

$$M_{\text{пр}} = (F_{\text{в}0} + \Delta F_{\text{в}}) k_1 l_{\text{в}} + F_{\text{к}} l_{\text{к}} k, \qquad (12\text{-}11)$$

where $F_{\text{в}0}$ — the force, necessary for the overcoming of the initial effort/force of return spring, $\Delta F_{\text{в}}$ — the force, necessary for displacing the return spring for the value of the freewheeling escapement of armature, and $F_{\text{к}}$ — pressure in the breaking contact.

After converting all torque/moments to the forces, led to the pusher (backstop) of armature, we find from the equation of the equilibrium of these forces formula for determining the value of acceleration, with which the relay will auto/self-wear/operate:

$$n_1 = \frac{kF_{\text{к}} \frac{l_{\text{к}}}{l_2} + k_1 (F_{\text{в}0} + \Delta F_{\text{в}}) \frac{l_{\text{в}}}{l_3}}{Q_{\text{я}} \frac{l_{\text{я}}}{l_1} + k Q_{\text{к}} \frac{l_{\text{к}}}{l_2} + \frac{3}{8} \left( kQ_{\text{кп}} \frac{l_{\text{кп}}}{l_2} + k_1 Q_{\text{вп}} \frac{l_{\text{вп}}}{l_3} \right)}, \qquad (12\text{-}12)$$

where $l_1$ — Distance from rotational axis to the pusher of armature, $l_2$ — distance from the bearing edge of contact spring to pusher and $l_3$ — distance from the bearing edge of return spring to pusher.

If uniform acceleration is directed in the plane of springs, then its action on contacts and the distributed masses of springs can be disregarded.

In this case expression (12-12) is simplified:

$$n_2 = \frac{k \frac{l_K}{l_3} F_K + k_1 \frac{l_n}{l_3} (F_{n0} + \Delta F_n)}{Q_n \frac{l'_n}{l_1}}, \qquad (12\text{-}13)$$

where $l'_n$ – the distance between centers of rotation and the center of gravity of armature in the direction, which corresponds to the new direction of acceleration force.

These formulas are derived T. K. Shtremberg.

Substituting in expressions (12-12) and (12-13) the nominal values of the effort/forces of contact and return springs, weights and distances, we will obtain the most probable values of the accelerations of auto/self-function in two mutually perpendicular planes.

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If we instead of the nominal substitute the minimum values of effort/forces $F_{\text{к}}$ and $F_{\text{в}}$ and of distances $l_{\text{к}}, l_{\text{в}}$ and $l_1$ and, on the contrary, the maximum values of weights $Q_{\text{я}}, Q_{\text{к}}, Q_{\text{кп}}$ and $Q_{\text{вп}}$ and distances $l_{\text{я}}, l'_{\text{я}}, l_{\text{кп}}$ and $l_{\text{вп}}$, then by formulas (12-12) and (12-13) it is possible to obtain the minimum values of the uniform accelerations of the auto/self-function of relay.

To Fig. 12-15, are given the distribution curves of the contact pressure of the breaking contact of the relay of types RES6, RES9 and RES10. From these curves it follows that the pressure in the contacts of relay and, therefore, the stability of relay to the effect of uniform accelerations change over wide limits.

The integral distribution curves of the minimum values of the uniform accelerations, calling the "auto/self-function" of the relay of types RS-13, RMU, RES6, RES9 and RES10, are shown to Fig. 12-16. From these curves it is evident that the law of the distribution of the minimum accelerations of auto/self-function is close to normal. Relays of the type RES6 with two stud switches auto/self-wear/operate during accelerations from 44 to 212 g. The mathematical expectation of the acceleration of the auto/self-function of these relays is equal to 126 g, and

the root-mean-square deviaticn of acceleration is 33 g(26.2o/o).

The greatest stability to the effect of uniform accelerations has a relay of the type RES10 (from 90 to 294 g).

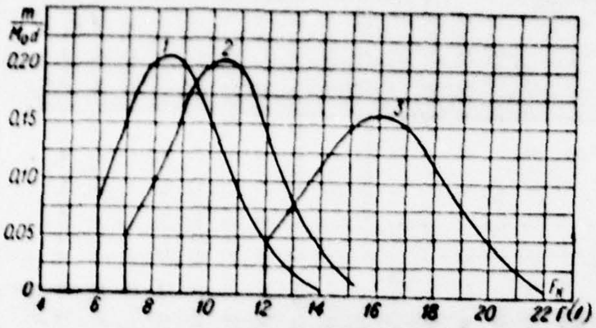


Fig. 12-15. The distribution curves of pressure in the breaking contact of relay. 1 - type RES10: $\bar{F}_K = 8,6$ g, e = 1.84 g, $N_0$ = 64; 2 - type RES9: $\bar{F}_K = 10,3$ g, e = 1.94 g, $N_0$ = 100; 3 - type RES6: $\bar{F}_K = 16$ g, e = 2.48 g, $N_0$ = 64.

Key: (1). g.

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During effect of uniform acceleration with value 25 g average current of the function of relay of the type RES6 with two stud switches changes by 7.6o/o of, those of cothe type RES9 - to 9.3o/o of, those of the type RES10 - to 1.6o/o of, those of the type RMU with two stud

switches - to 10.5o/o and the type of RS-13 with one closing and one breaking contact - to 24.4o/o.

With the ampere-turns, not calling the saturation of magnetic circuit, an increase in the spill current under the action of uniform acceleration has a dependence on the value of acceleration, close to linear.

A decrease in average current of release/tempering under the effect of uniform acceleration by value 25 g on relay of the type RES6 is equal to 9.8o/o, the type RES10 - 6.2o/o, the type of RMU - 9.8o/o and the type of RS-13 - 31.1o/o.

The dependence of reduction in current of the release/tempering of relay on the value of acceleration has more complex character.

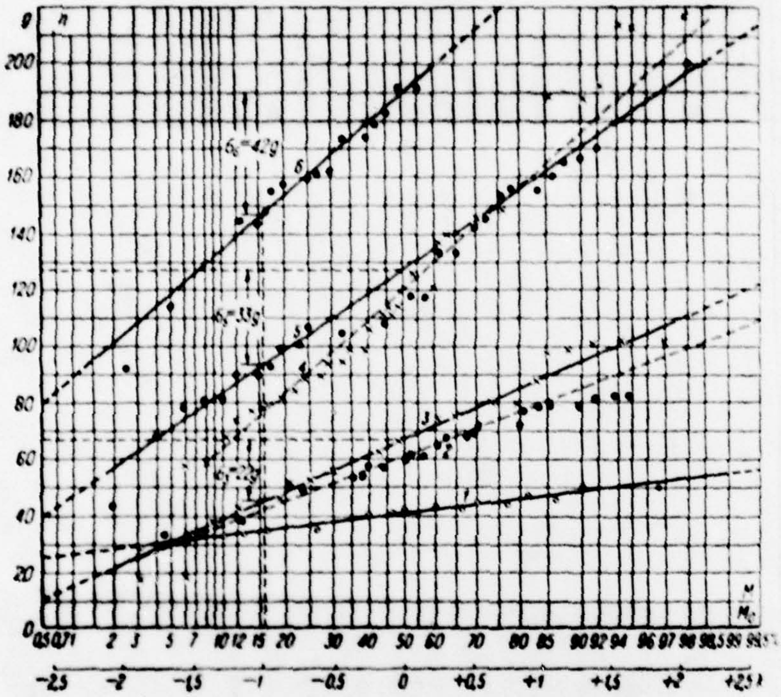


Fig. 12-16. The distribution curves of the minimum values of the uniform accelerations, calling the "auto/self-function" cf relay. 1 - type RS-13, load 1a+1p, $\bar{n}$ = 40g, $\sigma$ = 6 g; 2 - type RMU, load 2n, $\bar{n}$ = 60 g, $\sigma$ = 18 g; 3 - type RMU, load 4n, $\bar{n}$ = 67 g, $\sigma$ = 22 g; 4 - type RES9, load 2n, $\bar{n}$ = 120 g, $\sigma$ = 43 g; 5 - type RES6, load 2n, $\bar{n}$ = 126 g, $\sigma$ = 33 g; 6c type RES10, load 1n, $\bar{n}$ = 190 g, $\sigma$ = 42 g.

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The root-mean-square deviation of the spill current of these types of relay under normal conditions is within the limits from 4.3 to 11.0o/o, while that of the current of release/tempering is from 12.2 to 20o/o.

The investigation of the effect of uniform accelerations on the work of relay is made T. K. Shtremberg, by D. V. Gayevskoy and by Ye. D. Plyukhinoy.

During tests on centrifuge, the constant value acceleration, which operates on relay, can be determined from the following formula:

$$n = 11{,}17 \cdot 10^{-6} N^2 r, \qquad (12\text{-}14)$$

where N is number of revolutions of centrifuge per minute and

r - distance from the rotational axis of the armature of relay to the rotational axis of centrifuge in cm.